



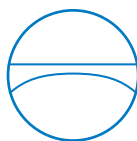
DEPARTMENT OF CIVIL, GEO AND  
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Master's Thesis

**Modeling and Evaluating a Truck  
Parking Information Management  
System Using Microscopic Traffic  
Simulation: A Case Study of the  
New York State Thruway**

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## MASTER'S THESIS

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**Topic: Modeling and Evaluating a Truck Parking Information Management System Using Microscopic Traffic Simulation: A Case Study of the New York State Thruway**

Predicting parking occupancy is a key need for the trucking industry. Increasing truck traffic volumes, heightening safety concerns, decreasing truck parking availability, shifting truck operator attitudes, and changing regulatory influences in the United States provide a rationale for truck parking information management systems (TPIMSs). TPIMSs monitor truck parking occupancy and deliver real-time parking information to operators and/or dispatchers.

New York State (NYS) has reported truck parking shortages at public travel plazas in addition to trucks illegally parking along freeway shoulders, at freeway interchange ramps, in local commercial areas, and on local streets near freeways. In this case, information on truck parking availability could alleviate the asymmetric information problem that operators face when looking for parking.

The goal of this research is to explore the use of PTV Vissim to model truck parking demand to simulate and evaluate a TPIMS on the NYS Thruway, a system of limited-access highways in the State. To achieve this goal, the following two research questions and their corresponding objectives were established.

Research question 1: Focusing on the NYS Thruway, how can truck parking demand be modeled using the microscopic traffic flow simulation software PTV Vissim?

Objectives:

- Investigate previous studies to find methodologies for truck parking demand modeling in traffic flow simulation software.

- Recommend a methodology for employing PTV Vissim to model truck parking demand.

Research question 2: Focusing on the NYS Thruway and using the microscopic traffic flow simulation software PTV Vissim, how can a TPIMS be modeled and what are its impacts on the number of truck parking violations?

Objectives:

- Model the NYS Thruway and selected travel plazas in PTV Vissim.
- Conduct a scenario analysis using the software where both the existing situation (No Build Scenario) and one with a TPIMS (TPIMS Scenario) are modeled and evaluated.

The student will present intermediate results to the mentor(s) Prof. Dr.-Ing. Rolf Moeckel and Dr. Ana Tsui Moreno Chou in the fifth, tenth, 15th and 20th week. The student will submit one copy for each mentor plus one copy for the library of the Focus Area Mobility and Transport Systems. Furthermore, the student will provide a PDF file of the master thesis for the website of this research group. In exceptional cases (such as copyright restrictions do not allow publishing the thesis), the library copy will be stored without public access and the PDF will not be uploaded to the website.

The student must hold a 20-minute presentation with a subsequent discussion at the most two months after the submission of the thesis. The presentation will be considered in the final grade in cases where the thesis itself cannot be clearly evaluated.



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Prof. Dr.-Ing. Rolf Moeckel



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Dr. Ana Tsui Moreno Chou

I hereby confirm that the presented master's thesis work has been done independently and using only the sources and resources as are listed. This thesis has not previously been submitted elsewhere for purposes of assessment.

Munich, December 19, 2017

Jared Lawrence Best



# Abstract

The United States (U.S.) economy heavily relies on truck drivers, who are exposed to a plurality of work-related stressors like ergonomic hazards, delivery pressures, irregular shifts, and hours-of-service regulations. In light of these stressors, it is crucial that truck operators find available parking when they need it. Focusing on New York State (NYS), more than half of its travel plazas and rest areas are faced with truck parking shortages at night, and many experience demand far in excess of supply.

Truckers can better locate safe and legal parking to rest if they have knowledge of the location of available parking. Increasing truck traffic volumes in the U.S., heightening safety concerns, decreasing truck parking availability, shifting truck operator attitudes, and changing regulatory influences provide a rationale for truck parking information management systems (TPIMSs). TPIMSs monitor parking occupancy and deliver real-time parking availability information to truck operators and/or dispatchers.

Microscopic traffic flow simulation could provide insight into the impact of implementing a TPIMS before construction. However, there is limited guidance on using microscopic simulation to model truck parking demand as well as to simulate and evaluate a TPIMS along a highway. This thesis explores and lays the foundation for using PTV Vissim to model truck parking demand using the example of the NYS Thruway, a system of limited-access highways in NYS. With a focus on this highway system, PTV Vissim was also employed to model and evaluate a TPIMS.

The purpose of this thesis is to demonstrate the applicability and general methodology of how PTV Vissim may be used to perform a detailed analysis of truck parking demand and the influence of a TPIMS for highway systems such as the NYS Thruway underlying this work. It was found that it is possible to perform truck parking demand analysis in PTV Vissim. As far as the author is aware, this is the first work that provides a framework for employing PTV Vissim for such an analysis. Generally, it was possible to evaluate a TPIMS using PTV Vissim, but limitations with the software and the lack of available data required a set of model assumptions that have to be further validated.

With the focus being on demonstrating the applicability of PTV Vissim of modeling a TPIMS, the results for the NYS Thruway are only exemplary. They provide neither a thorough scenario analysis that yields best possible estimates of truck parking demand nor a full evaluation of a TPIMS on the NYS Thruway in the sense of an expert survey report. Collection of necessary empirical data and calibration of the corresponding model assumptions were outside the scope of this work, and all results should therefore be interpreted accordingly. Nonetheless, the methodology elaborated in this thesis serves as a fruitful starting point to perform such an in-depth case study assessment in future work.

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# List of Abbreviations

**AASHTO** American Association of State Highway and Transportation Officials

**API** application programming interface

**ATA** American Trucking Associations

**CDOT** Colorado Department of Transportation

**CFR** Code of Federal Regulations

**CMV** commercial motor vehicle

**COM** Component Object Model

**CVSA** Commercial Vehicle Safety Alliance

**DMS** dynamic message sign

**DOT** department of transportation

**DTA** dynamic traffic assignment

**EB** eastbound

**FAF** Freight Analysis Framework

**FHWA** Federal Highway Administration

**FMCSA** Federal Motor Carrier Safety Administration

**FVD** floating vehicle data

**GDP** gross domestic product

**GPS** global positioning system

**HGV** heavy goods vehicle

**HOS** hours-of-service

**HPMS** Highway Performance Monitoring System

**I-190** Interstate 190

**I-287** Interstate 287

<b>I-81</b>	Interstate 81
<b>I-87</b>	Interstate 87
<b>I-90</b>	Interstate 90
<b>IDS</b>	information delivery system
<b>ITS</b>	intelligent transportation system
<b>MAASTO</b>	Mid America Association of State Transportation Officials
<b>mph</b>	miles per hour
<b>NATSO</b>	National Association of Truck Stop Operators
<b>NB</b>	northbound
<b>NCHRP</b>	National Cooperation Highway Research Program
<b>NHS</b>	National Highway System
<b>NJTPA</b>	North Jersey Transportation Planning Authority
<b>NYC</b>	New York City
<b>NYMTC</b>	New York Metropolitan Transportation Council
<b>NYS</b>	New York State
<b>NYSDOT</b>	New York State Department of Transportation
<b>NYSTA</b>	New York State Thruway Authority
<b>OD</b>	origin-destination
<b>OOIDA</b>	Owner-Operator Independent Drivers Association
<b>PGS</b>	parking guidance system
<b>SB</b>	southbound
<b>TPIMS</b>	truck parking information management system
<b>U.S.</b>	United States
<b>USDOT</b>	United States Department of Transportation
<b>VMS</b>	variable message sign
<b>VMT</b>	vehicle miles traveled
<b>WB</b>	westbound

# 1. Introduction

Freight trucks are a major driving force of the United States (U.S.) economy. According to the American Trucking Associations (ATA, 2017) as well as Worth, Guerrero, and Meyers (2016), trucks are responsible for around 70% of all the freight tonnage moved in the country. Truck operators must endure long hours on the road involving a multitude of work-related stressors, such as ergonomic hazards, delivery pressures, and irregular shifts (Hege et al., 2015). In this regard, providing an adequate supply of truck parking is both of economic interest and a safety concern. However, recent studies that focused on the adequacy of truck parking in the U.S. have documented truck parking shortages while growth in commercial motor vehicle (CMV) traffic on the National Highway System (NHS) is projected (Federal Highway Administration [FHWA], 2015). Additionally, they have concluded that truck drivers lack information about the parking occupancy at travel plazas and rest areas.

Accounting for about 8% of the U.S. gross domestic product (GDP), New York State (NYS) is considered the third strongest economy in the country (Bureau of Productivity Analytics [BPA], 2015). Focusing on this state alone, more than half of its travel plazas and rest areas are faced with truck parking shortages at night, and many experience demand far in excess of supply, resulting in trucks parking on ramp shoulders and on car parking spaces (FHWA, 2012). Other studies have also reported issues resulting from truck parking shortages in NYS; see, for example, FHWA (2015) or the New York Metropolitan Transportation Council (NYMTC, 2009).

In a report prepared for the Federal Motor Carrier Safety Administration (FMCSA), Smith, Baron, Gay, and Ritter (2005) studied truck parking challenges and identified two potential solutions to parking shortages: increase parking supply and better match supply and demand in places where shortages occur. They argue that although the former is the more direct solution, the latter is more cost-effective and would better distribute parking demand along highway corridors.

Knowledge of the location of available parking can mitigate the asymmetric information problem that truck drivers face when looking for parking (Transportation Sustainability Research Center [TSRC], n.d.). With such information, truckers can better locate safe and legal parking to rest. According to Perry, Oberhart, and Wagner (2015), increasing truck traffic volumes in the U.S., height-



ening safety concerns, decreasing truck parking availability, shifting truck operator attitudes, and changing regulatory influences provide a rationale for truck parking information management systems (TPIMSs). TPIMSs, which are sometimes referred to as simply *truck parking management systems* in the literature, monitor CMV parking occupancy and deliver real-time parking availability information to truck operators and/or dispatchers.

Microscopic traffic flow simulation (or commonly *microsimulation*) could provide insight into the impact of implementing a TPIMS before construction. However, as is further discussed in the literature review of this thesis in Chapter 3, there is limited guidance on using microscopic simulation to model truck parking demand as well as to simulate and evaluate a TPIMS along a highway. To address this gap, this thesis explores and lays the foundation for using the microscopic simulation software PTV Vissim—referred to as only *Vissim* throughout this work—to model truck parking demand using the example of the NYS Thruway, a system of limited-access highways in NYS. With a focus on this highway system, Vissim was also employed to model and evaluate a TPIMS.

To achieve the goal of a full and comprehensive demonstration of how to model and evaluate truck parking demand as well as a TPIMS in Vissim, the following two research questions and their corresponding objectives were established.

**Research question 1:** Focusing on the NYS Thruway, how can truck parking demand be modeled using the microscopic traffic flow simulation software Vissim?

Objectives:

- Investigate previous studies to find methodologies for truck parking demand modeling in traffic flow simulation software.
- Recommend a methodology for employing Vissim to model truck parking demand.

**Research question 2:** Focusing on the NYS Thruway and using the microscopic traffic flow simulation software Vissim, how can a TPIMS be modeled and what are its impacts on the number of truck parking violations?

Objectives:

- Model the NYS Thruway and selected travel plazas in Vissim.
- Conduct a scenario analysis using the software where both the existing situation (No-build Scenario) and one with a TPIMS (TPIMS Scenario) are modeled and evaluated.

The purpose of this thesis is to demonstrate the general methodology of how Vis-sim may be used to perform such an in-depth study. It is not to provide highly accurate estimates of truck parking demand nor to conduct an overly thorough scenario analysis of a TPIMS on the NYS Thruway. Approximating potentially realistic behavior was an aim of this work, but case studies require empirical input for model calibration and validation, which this thesis work did not entail. Therefore, all numbers reported herein should be approached with caution.

The current work is reported in the rest of the document as follows. The next chapter, Chapter 2, provides essential background information for this thesis. Chapter 3 discusses previous studies related to this work. Following a discussion in Chapter 4 on the scope and data used in the current work, Chapter 5 outlines the methodology of this study. After the results are discussed in Chapter 6, Chapter 7 concludes this thesis by summarizing its main contributions and listing the limitations of the study as well as recommendations for future work. Appendices contain supplementary information.

## 2. Background

This chapter provides essential background information for the current work. The first section outlines hours-of-service (HOS) regulations, which set the allowable working hours of truck drivers and must be considered to adequately model both truck parking demand as well as a TPIMS in microscopic traffic flow simulation software. In the subsequent section, the Jason's Law Truck Parking Survey, a survey that documented CMV parking shortages at public and private facilities along the NHS, is discussed (FHWA, 2015). Afterwards, a general description of the operation and components of TPIMSs is provided, and three TPIMS implementations are discussed. Ending this chapter is a summary of benefits and drawbacks of TPIMSs.

### 2.1. Hours-of-service regulations

HOS regulations in the U.S. are issued by FMCSA of the United States Department of Transportation (USDOT) and set the allowable working hours of CMV drivers (Federal Motor Carrier Safety Administration [FMCSA], 2017). Generally, a CMV, which is also referred to as a heavy goods vehicle (HGV), is a vehicle that is used for business purposes and fits any of these descriptions: weighs 10,001 pounds or more, is designed to transport 16 or more people not for compensation, is designed to transport nine or more people for compensation, or is carrying hazardous materials in bulk requiring placards (FMCSA, 2017). These regulations are detailed in the Code of Federal Regulations (CFR), specifically in the Hours of Service of Drivers, 49 CFR Section 395 (2017).

A list of terms and their definitions are introduced in 49 CFR § 395.2, aptly named *Definitions*. Applying the same meanings, two terms in particular are used throughout the current work: *driving time* and *on-duty time*. Driving time means the time spent at the driving controls of a CMV in operation, whereas on-duty time means the total amount of time from when the driver begins working or is required to be ready to work until the driver is relieved from all responsibility for performing work.

The summary of the regulations below is from 49 CFR § 395.3, in which the maximum allowable driving time for property-carrying vehicles is presented. These regulations include further stipulations that are out of the scope of this thesis and, therefore, are not outlined below. The interested reader is directed towards 49 CFR § 395 for the complete set of regulations in their original form.

### Summary of HOS regulations:

- ***Start of work shift:*** A driver may drive only after first taking 10 consecutive hours off duty.
- ***14-hour period:*** A driver may drive only during a period of 14 consecutive hours after coming on duty following the 10 consecutive hours off duty. The driver may not drive after the end of the 14-consecutive-hour period without first taking 10 consecutive hours off duty.
- ***11-hour driving limit:*** A driver may drive a total of 11 hours during the 14-hour period.
- ***Rest breaks:*** A driver may not drive if more than 8 hours have passed since the end of the driver's last off-duty or sleeper-berth period of at least 30 minutes.
- ***60-hour on-duty limit:*** A driver may not drive after 60 hours on duty in 7 consecutive days.
- ***70-hour on-duty limit:*** A driver may not drive after 70 hours on duty in 8 consecutive days.
- ***34-hour restart:*** A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty.

Discussing the importance of HOS regulations is outside the scope of this thesis. However, the reader may refer to Jovanis, Wu, and Chen (2011), who “performed both qualitative and quantitative analyses of commercial motor vehicle driver hours of service to assess the implications of particular policies on the odds of a crash” (Jovanis et al., 2011, p. 63).

## 2.2. Jason's Law Truck Parking Survey

The Moving Ahead for Progress in the 21st Century (MAP-21; P.L. 112-141) law became in effect on October 1, 2012, and prompted the Jason's Law Truck Parking Survey (FHWA, 2015). An aim of this survey was to document CMV parking shortages at public and private facilities along the NHS (FHWA, 2015). Additionally, it was to “[e]valuate the capability of each State to provide adequate parking and rest facilities for commercial motor vehicles engaged in interstate transportation; [a]ssess the volume of commercial motor vehicle traffic in each State; and [d]evelop a system of metrics to measure the adequacy of commercial motor vehicle parking facilities in each State” (FHWA, 2015, p. 1). This section summarizes the findings of the Jason's Law Truck Parking Survey that are relevant to the current work and is solely based on FHWA (2015). For additional findings of this survey, which are supplemental to the current work, refer to Appendix A.

In order to evaluate each State's capability of providing adequate parking, the Federal Highway Administration (FHWA) coordinated with public and private stakeholders to develop surveys of each State's department of transportation (DOT) and motor carrier safety officials. Information from questionnaires to other stakeholders, including truck driver representatives as well as travel plaza and truck stop owners and operators, supplemented the surveys. The current work adopts the same definition of *capability* as in the Jason's Law Truck Parking Survey report, which is the relationship of parking supply with key indicators of demand, such as lack of capacity (shortages), illegal parking, and number of spaces in relation to vehicle miles traveled (VMT).

The following list, which is divided by theme, outlines key findings of the survey that pertain to the current work.

### Driver preferences:

- Drivers are most interested in maximizing the driving hours and distance traveled during their hours of service.

### Parking supply:

- When asked if truck parking shortages have been observed at public travel plazas, NYS reported "Yes".
- When asked if truck parking shortages have been observed at private truck stops, NYS reported "No".
- Out of all States that reported the number of public truck parking spaces per 100 miles of NHS, NYS is in the lowest quartile.
- Out of all States that reported the number of private truck parking spaces per 100 miles of NHS, NYS is in the lowest quartile.

### Parking capacity:

- Truck parking peak demand generally occurs during overnight periods when parking needs tend to be highest.
- Independent truck drivers belonging to the Owner-Operator Independent Drivers Association (OOIDA) were surveyed and asked to identify States with parking shortages. 49% of respondents indicated NYS, making it the second most mentioned State within this survey group with truck parking shortages after New Jersey.
- Trucking industry drivers belonging to the American Trucking Associations (ATA) were surveyed and asked to identify States with parking shortages. 42% of respondents indicated NYS, making it the third most mentioned State within this survey group with truck parking shortages.



- Trucking industry management and logistics personnel belonging to the ATA were surveyed and asked to identify States with parking shortages. 37% of respondents indicated NYS, making it the third most mentioned State within this survey group with truck parking shortages.

### Unofficial parking observances:

- When asked if trucks have been observed parking along freeway shoulders, NYS reported “Yes”.
- When asked if trucks have been observed parking at freeway interchange ramps, NYS reported “Yes”.
- When asked if trucks have been observed parking in local commercial areas, NYS reported “Yes”.
- When asked if trucks have been observed parking on local streets near freeways, NYS reported “Yes”.
- Unofficial parking is mostly observed during night hours during weekdays.
- Unofficial parking is consistent throughout the year with only a slight decline in winter months.

### Driver perceptions:

- “More than 75 percent of truck drivers and almost 66 percent of logistics personnel reported regularly experiencing problems with finding safe parking locations when rest was needed” (FHWA, 2015, p. viii).
- 90% reported that finding safe and available parking during night hours is a struggle.
- “Drivers and logistics personnel reported that the parking shortages were encountered mostly during the weekdays, but many reported weekend difficulties” (FHWA, 2015, p. viii).
- “Months of the year when problems occurred were generally consistent; however, the ATA drivers reported fewer problems during the summer months while their logistics personnel counterparts reported higher challenges during this time” (FHWA, 2015, p. viii).

### Communication improvements to alert drivers of parking occupancy:

- Predicting parking occupancy is a key need for the trucking industry.
- The industry is adopting technology and developing apps to inform truckers in advance about parking occupancy at some facilities.

These findings demonstrate that NYS does not have the capability of providing adequate truck parking. With reference to the second research question of this work, what should be highlighted is the final point above, which is that the trucking industry is adopting technology to deliver parking availability information to truck drivers.

### **2.3. Truck parking information management systems**

TPIMSs monitor CMV parking occupancy and deliver real-time parking availability information to operators and/or dispatchers. These systems generally consist of two components: data collection and information dissemination (Colorado Department of Transportation [CDOT], 2016). For data collection, the most common technology to determine whether a truck parking spot is available or occupied is video detection; however, magnetic, thermal, laser, and radar sensors are also implemented (Perry et al., 2015; Washburn, Sun, & Stoop, 2016). As for disseminating the information to operators and/or dispatchers, one or several of the following technologies are used: variable message signs (VMSs), which are also referred to as dynamic message signs (DMSs); websites; smart-phone applications; in-cab signals; and radio (Perry et al., 2015).

The remainder of this section discusses three TPIMS projects, addressing how these systems operate in practice, how much they generally cost, and who are the typical stakeholders in such projects.

#### **2.3.1. Mid America Association of State Transportation Officials Regional Truck Parking Information Management System**

The U.S. states of Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Ohio, and Wisconsin have joined together to realize the Mid America Association of State Transportation Officials (MAASTO) TPIMS Project, which aims to develop a real-time, multi-state TPIMS (Moore, 2016). For the planned deployment corridors of the project, see Figure 2.1. As claimed by Moore (2016), the system is scheduled to be fully deployed in Fall 2018, and the entire project is expected to be concluded at the end of 2019 after a full year of success measures tracking.




Figure removed due to possible copyright infringements.

Figure 2.1.: The MAASTO TPIMS Project deployment corridors (Moore, 2016).

According to Moore (2016), the project is funded through a \$25 million Federal TIGER grant and state funds and will cost \$28.6 million (in 2015 dollars). However, Moore (2016) states that the project is expected to generate more than \$403 million in total benefits. Moore (2016) argues that fewer non-routine maintenance repairs will need to be completed since better parking information will mean less unauthorized parking on highway ramps and shoulders, which are generally not designed for CMV parking. Furthermore, he claims that the system will facilitate economic growth by providing more efficient movement of goods and that less fuel will need to be consumed since truck drivers will spend less time looking for parking.

Moore (2016) states that the MAASTO TPIMS initiative will deliver a consistent, cohesive parking-availability system to truck drivers even when they cross state borders. This will be achieved through routinely gathering and delivering parking availability information through a common application programming interface (API). The states involved in the project “will have the flexibility to integrate proposed solutions into their existing transportation information systems” (Moore, 2016, p. 1).

### **2.3.2. Colorado Truck Parking Information Management System**

The Colorado Department of Transportation (CDOT) recognized the need for truck drivers to have access to real-time information on parking as well as roadway conditions and has proposed the Colorado TPIMS, which will begin construction in January 2018 and cost \$9 million (CDOT, 2016). Applying multiple technologies, this system will monitor commercial and public parking availabil-

ity, deliver parking availability information to operators and dispatchers, and facilitate parking reservations (CDOT, 2016). All subsequent information presented in this section is based on CDOT (2016).

To support participation with surrounding states, the Colorado TPIMS will be developed in such a way to allow for expandability, interoperability, and modularity. The CDOT is planning for the project to be integrated into a larger multi-western state truck parking system. The CDOT reports that the project will align with the MAASTO TPIMS approach.

The Colorado TPIMS would have a net positive economic impact. Freight delivery reliability would be improved as well as the shipping time efficiency. Furthermore, costs and delays associated with truck operators searching for parking or winter chain-up areas would be reduced.

The Colorado TPIMS Project will neither add new truck parking facilities nor increase the parking supply at existing the facilities, but rather it will utilize advanced intelligent transportation system (ITS) technology to optimize utilization at current truck parking facilities. Collecting data with sensors and cameras, the planned system will deliver information to truck drivers with the aim of distributing trucks across many available parking areas. This could potentially eliminate overcrowding, which often causes trucks to park at illegal locations, such as on rest area ramps or on roadway shoulders.

DMSs will be used to provide truck drivers with real-time truck parking information at public and private parking facilities. The plan is to merge static signs, which will include information about the parking facility such as type and exit number, and VMS signs that will display the available truck parking spots; see Figure 2.2 below.




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Figure 2.2.: The Colorado TPIMS Project sign design (CDOT, 2016).

### 2.3.3. Pilot project in Bavaria, Germany

As this thesis focuses on the U.S. context, the previous discussions on U.S. TPIMS projects are most relevant; however, it is still worthwhile to briefly discuss a TPIMS project abroad, so that the reader understands that the implementation of these systems is also occurring in other countries.

According to Siemens AG (2015), as there is a lack of approximately 11,000 truck parking spaces on German highways, Siemens installed a TPIMS to test if the system could reduce the effort needed to find available truck parking. The first pilot project started on the A9 between Nuremberg and Munich in May 2015. The system utilizes intelligent sensors to identify free parking spaces and enables truck drivers to better plan their rest periods, resulting in improved safety for all motorists. On behalf of the Bavarian Ministry of the Interior, for Building and Transport, Siemens installed the TPIMS at 14 of the 21 rest areas, which delivers parking availability information on around 600 truck parking spaces directly into cabs. Laser scanners at rest area entrance and exit points determine the dimensions of passing vehicles, and other sensors embedded in the road surface measure speed, length, and direction. Combining this information allows vehicle counts and classes to be collected. For more information on this project, see Siemens AG (2014).



### 2.3.4. Benefits and drawbacks

Based on the TPIMS projects discussed coupled with other literature reviewed in this thesis work, the following is a non-exhaustive list of benefits and drawbacks of TPIMSs.

#### Benefits:

- ***Improved parking demand management:*** Informing truck drivers about available parking spaces is one effective measure in managing increasing parking demand since these systems distribute the demand along highway corridors; see e.g. Smith et al. (2005) or Trombly (2003).
- ***Decreased congestion:*** The CDOT (2016) reports that in urban areas, truck drivers using TPIMSs spend less time cruising for parking. This reduced truck volume results in less congestion on urban streets.
- ***Reduced pavement degradation:*** According to the CDOT (2016), overcrowding at truck parking facilities, which in turn forces drivers to park at locations not designed to support CMV parking, may lead to pavement degradation. Pavement on shoulders and ramps is generally not intended to support truck parking. When these areas are routinely being used for parking, the pavement degrades more quickly, leading to the need for more frequent and expensive repairs. With TPIMSs, truck operators are aware of the parking availability at locations in advance and can better plan their routes to avoid parking at illegal locations.
- ***Reduced fuel consumption:*** Moore (2016) claims that truckers consume less fuel with TPIMSs due to less time spent cruising for parking.
- ***Economic benefits:*** According to Moore (2016), the economic benefits of rolling out a TPIMS project can be extensive, resulting from improved efficiency of logistics.

#### Drawbacks:

- ***Capital cost:*** In a report synthesizing information from several TPIMS projects, Perry et al. (2015) show the capital costs of four projects, which all implemented different detection and communications technologies. Based on the presented data, the average capital cost per truck parking facility ranges from \$408,188.00 to \$2,435,844.00.
- ***Maintenance cost:*** Based on the same report and specifically focusing on one TPIMS project in the state of Michigan, the average annual maintenance cost per truck parking facility is around \$26,781.50.
- ***Unaltered parking supply:*** In cases of extreme truck parking demand, a TPIMS alone might not be capable of handling the demand, and thus, additional parking supply would still be required.

## 3. Literature Review

This chapter explores previous studies on both general and truck parking demand modeling using microscopic traffic simulation. Furthermore, it discusses work, or the lack thereof, on both general and truck parking information management system modeling using microsimulation. The literature review indicated—to the author’s best knowledge—that there is sparse literature on the subject of this thesis, which is acknowledged at the end of this chapter. Thus, the author argues that this work is novel, laying the foundation from which future research can expand upon.

### 3.1. General parking demand modeling

Despite the fact that parking demand has been widely studied, only a handful of studies that specifically used microscopic traffic simulation to investigate this topic were identified. This section summarizes these studies, drawing appropriate insights from them to form the foundation of the current work.

In a paper, Fries, Chowdhury, and Dunning (2012) present an approach for evaluating the mobility impact of relocating parking at Clemson University in South Carolina using dynamic traffic assignment (DTA) within a microscopic traffic simulation model. They observed that most previous studies used DTA with mesoscopic simulation models and that there is limited guidance on the application of DTA within microscopic models. Fries et al. (2012) developed a traffic simulation model in Vissim and proposed a DTA-based simulation framework for modeling parking demand. Their model was applied to a case study, which considered changes in traffic patterns and volumes resulting from university parking alterations. Although the researchers identified challenges with using Vissim and thus indicated limitations with the study, they concluded that their methodology was efficient and repeatable.

The work of Fries et al. (2012) provides some insight into the current work. Although Fries et al. (2012) did not focus on modeling truck parking, they applied DTA within the microscopic traffic simulation software Vissim and demonstrated that the software is to some degree capable of modeling the complexity of parking demand. This was taken as a motivation to use Vissim in the current study.

In another paper, Bischoff and Nagel (2017) address the challenge of integrating a parking search model into traffic simulation, which are currently not widely integrated. Using MATSim (Multi-Agent Transport Simulation), the parking search model was applied to a case study in an area of Berlin, Germany. MATSim was chosen since it is an agent-based, flexible, open-source software that offers a versatile base from which to extend the existing model with parking search behavior. Concerning the simulation extension and modification, Bischoff and Nagel (2017) used a combination of day-to-day and within-day replanning. Standard day-to-day replanning was applied for departure time choice (and mode choice), whereas within-day was used for adjusting route choice. Bischoff and Nagel (2017) argue that several factors attribute to a person's parking search behavior, such as the location, the cost of parking, personal experience, and so on. Therefore, they advise the search behavior to be agent-specific.

This thesis work can draw useful insights from the work of Bischoff and Nagel (2017). Their reasoning behind using agent-specific parking search behavior, which there seems to be no compelling reason to argue against, was taken into consideration in the current study. MATSim was also briefly taken into account as a potential modeling platform for the current work. However, as Vissim already offers a good foundation from which to build a truck parking demand model as well as a TPIMS model, this thesis work centered on it instead of MATSim.

### **3.2. Truck parking demand modeling**

To the best knowledge of the author, no substantial work has been done on truck parking demand modeling specifically using microscopic traffic simulation. Therefore, work related to truck parking demand modeling that did not utilize microsimulation was also considered in the literature review.

Using stepwise regression analysis and focusing on Interstate 81 (I-81) within Virginia, Garber, Wang, and Charoenphol (2002) developed a truck parking demand model that related parking accumulation at any given 30-minute interval with independent variables. The variables considered included the total number of trucks on the studied highway near a truck stop in half hour intervals, the percentage of trucks near a truck stop in half-hour intervals, the parking duration in half-hour intervals, and the distance from a truck stop to the studied highway. Two truck stops were randomly selected to validate the model. Future truck parking demand "was estimated by examining (1) the predicted maximum parking accumulation at the truck stops based on the models, (2) parking at rest areas, and (3) parking on interstate ramps or shoulders, which is illegal" (Garber et al., 2002, p. 11). Garber et al. (2002) found that the models are good prediction tools for truck parking along I-81 within Virginia based on the R-squared values.

However, the main limitation of their model is that it might not be suitable for parking demand modeling and forecasting along other highways since it was built with an extensive amount of data specific to I-81 in Virginia.

Another study worth attention is the work of Nourinejad, Wenneman, Habib, and Roorda (2014), who developed a method for investigating the impact of truck parking policy in urban areas. Nourinejad et al. (2014) created an econometric parking choice model that considers parking type and location, and they developed a traffic simulation module that takes into account the parking choice model to select suitable parking facilities. The models were applied to a case study on the Toronto Central Business District to evaluate the impact of dedicating on-street parking in a busy street system. The researchers concluded that “[t]he model is able to capture important dimensions of parking activity such as walking distance, congestion impact, and parking search times that are commonly neglected in the literature, and usually not quantified at all in practical decision-making” (Nourinejad et al., 2014, p. 12).

Although not directly related to this thesis work, there are some links between the work of Nourinejad et al. (2014) and this thesis. Nourinejad et al. (2014) applied traffic microsimulation software, specifically Paramics, to model the driving and parking behavior of individual vehicles. They extended the existing Paramics software using their own parking choice model and found that the model was credible, though could be further validated.

### **3.3. General parking information management system modeling**

As there is limited literature on TPIMS modeling using microscopic traffic simulation software, it is fruitful to review literature of a related topic: parking guidance system (PGS) modeling using microscopic traffic simulation software. A PGS is a “system of all the PGS signs implemented in a city to inform car drivers about the available number of parking spaces at the parking locations in a city” (Obdeijn, 2011, p. 9). This is an interesting topic to look at since the technology and concept of a PGS are similar to those of a TPIMS.

In a master’s thesis, Obdeijn (2011) developed a tool in S-Paramics, which is a microscopic traffic simulation software commonly used throughout the Netherlands. The tool models the impacts of PGSs on traffic performance. The developed PGS tool was used in a case study that focused on Den Helder in the Netherlands. Focusing on this area, Obdeijn (2011) simulated the difference between two future scenarios: one with an implemented PGS and one without. He found significant differences in traffic performance indicators. Due to car drivers rerouting to alternative parking lots, the duration that parking lots remain full

dropped by 19.8%. The simulation results indicated a total travel time reduction in one area near the city center by 4.3%, which is attributed to reduced waiting times at full parking lots. There was not a significant difference in traffic volumes between the two scenarios, mainly due the lack of congestion in the scenario without a PGS.

In the current work, it is of interest to conduct a scenario analysis, comparing the No-build Scenario with the TPIMS Scenario. Similar to this thesis, Obdeijn (2011) compared one scenario with an implemented system that provided drivers with parking availability information—in his case a PGS—and one without. Obdeijn (2011) chose the duration that parking lots remained full, or in other words, at capacity, as one key parameter for his comparison and found a substantial drop in this value with the implementation of a PGS. Partially owing to his selection of this parameter, this thesis work adopted the duration at capacity as an evaluation criterion for the scenario analysis.

### **3.4. Truck parking information management system modeling**

As far as the author is aware, no work that focused on TPIMS modeling using microscopic traffic simulation currently exists based on an extensive review of the literature. Therefore, all the work associated with TPIMS modeling using microscopic traffic simulation that is done within this thesis is considered novel.

## **4. Scope of Study and Data Characteristics**

This chapter discusses the scope of the current work, first introducing all major highways in NYS and then providing a specific overview of the NYS Thruway, which constitutes the underlying modeling framework in this thesis. As traffic flow data were not available for the entirety of the Thruway, attention is placed on explaining which sections of the highway and which travel plazas were modeled. Concluding this chapter is a description of the raw data available for this study.

### **4.1. Major highways in New York State**

Major highways in NYS are managed by both the New York State Department of Transportation (NYSDOT) and the New York State Thruway Authority (NYSTA). The former maintains over 16,000 miles of roads (New York State Department of Transportation [NYSDOT], 2008), whereas the latter maintains around 570 miles (New York State Thruway Authority [NYSTA], 2017b). For an overview of the state's major highways, see Figure 4.1 on the following page.



ley (in Western NYS), i.e. the total distance between NYC and Ripley is 496 miles. The remaining 74 miles are composed of connecting highways in the regions of NYC, Albany, and Buffalo. Annually, around 250 million vehicles drive 8 billion miles on the Thruway.

The Thruway facilitates travel between New England, the Midwestern U.S., the Southern U.S., and Canada. It makes direct connections with New Jersey's Garden State Parkway and Interstate 287 (I-287), the Connecticut and Massachusetts turnpikes, and other expressways that lead to New England, Canada, the Midwest, and the South (NYSTA, 2017a). "The Thruway includes Interstate 87 (New York City to Albany); Interstate 95 (New York City to Connecticut); Interstate 287 (connecting I-87 with I-95); Interstate 90 (both the Berkshire Spur, which connects I-87 with the Massachusetts Turnpike, and the mainline Thruway, which runs from Albany to the Pennsylvania border through Syracuse and Buffalo), and Interstate 190 (connecting Buffalo with Niagara Falls)" (NYSTA, 2017a).

The Thruway's 27 travel plazas are located every 30 to 40 miles along the Thruway (NYSTA, 2017b). Open 24 hours daily, these public travel plazas offer a host of services such as restaurants, filling stations, ATMs, tourist information centers, gift shops, travel information, and current weather and traffic conditions (NYSTA, 2017b). Furthermore, they provide both short and long-term parking to truck operators. Figure 4.2 below shows the routes belonging to the NYS Thruway as well as the locations of the system's 27 travel plazas. In the figure, it can be seen that the travel plazas Angola and New Baltimore are accessible by both directions of traffic. However, there is one key distinction between them. Angola includes two travel plazas, each on either side of the Thruway (eastbound (EB) direction and westbound (WB) direction). New Baltimore, on the other hand, is one travel plaza located on the southbound (SB) side of the Thruway, but is accessible by northbound (NB) traffic via on- and off-ramps and an overpass.



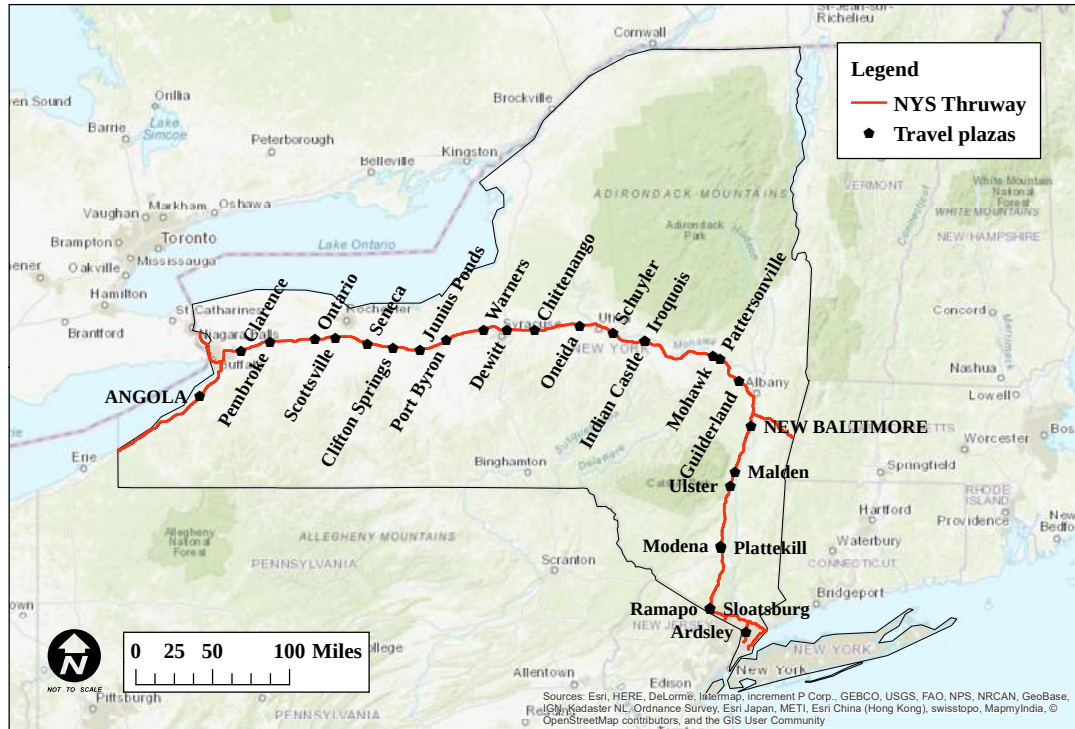


Figure 4.2.: NYS Thruway and travel plazas. Own illustration created with ArcGIS with data from ArcGIS Online (2015a, 2015b). Travel plaza names are displayed on the side of the Thruway corresponding to the direction of travel that can access them. Capitalized labels indicate travel plazas that can be accessed by both directions of traffic.

### 4.3. Spatial scope of study

Due to the lack of available data for sections of the Thruway that are not tolled (see Section 4.4), the spatial scope of this study was slightly reduced from the full extent to only the tolled parts of the Thruway and the corresponding travel plazas. This resulted in the slightly smaller self-contained highway system with well-defined network boundaries for the truck parking demand model and both models associated with the TPIMS modeling task, which were created in Vissim. Approximately 500 of the 570 miles of the NYS Thruway (or about 88%) were modeled in Vissim in this thesis work. As mentioned in Section 4.1, around 80% of truck parking is provided by privately-owned facilities. These facilities are not modeled in Vissim since they are located outside the bounds of the tolled section of the Thruway.

Figure 4.3 shows the sections of the NYS Thruway and travel plazas ultimately considered in the current work. Key differences to the full extent of the NYS Thruway in Figure 4.2 are the missing travel plaza Ardsley in addition to wing

sections of the Thruway near Buffalo and NYC. Note, however, that the main characteristic elaborated in the previous section, i.e. being a long-distance connector between these two cities and beyond, is still present in the network considered in this thesis. For convenience, the remainder of this work still refers to this network system underlying all models as simply the NYS Thruway.

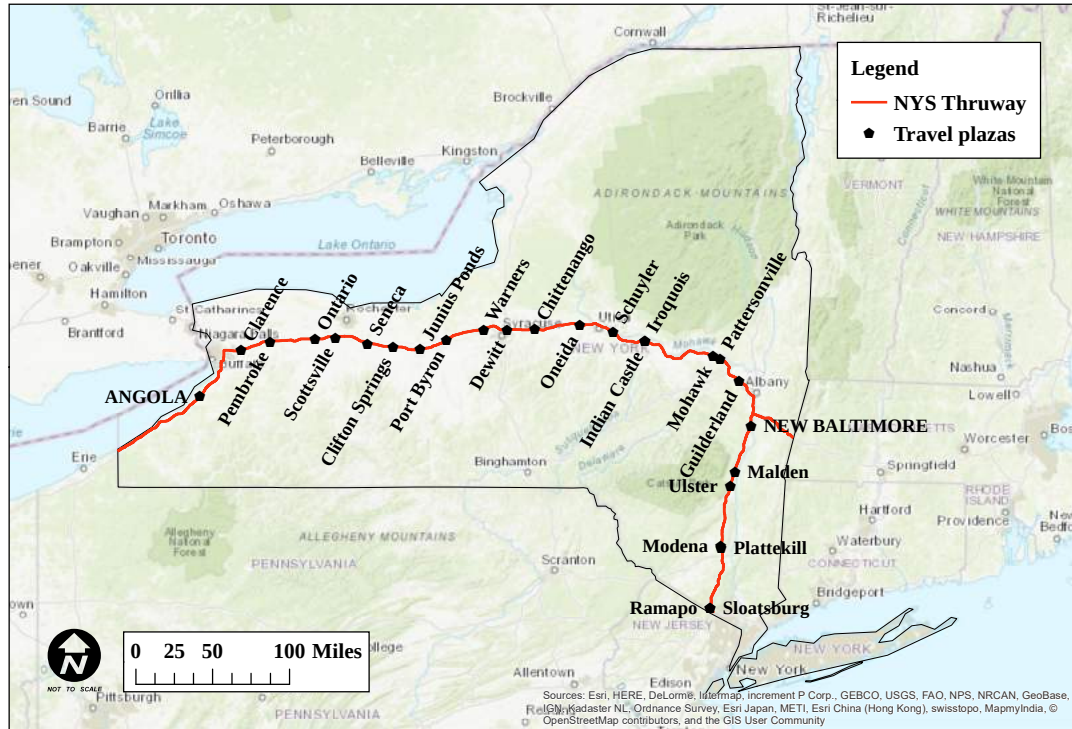


Figure 4.3.: Sections of the NYS Thruway and travel plazas considered in the current study. Own illustration created with ArcGIS with data from ArcGIS Online (2015a, 2015b). Travel plaza names are displayed on the side of the Thruway corresponding to the direction of travel that can access them. Capitalized labels indicate travel plazas that can be accessed by both directions of traffic.

Where highway entrance/exit points (or interchanges) are located is highly relevant in building the truck parking demand model and both models associated with the TPIMS model. Knowing the locations of economic activity gives insight into trucks' points of origin and their destinations. Figure 4.4 below shows a map of the entrance/exit points on the sections of the NYS Thruway considered in this work and their corresponding numbers.

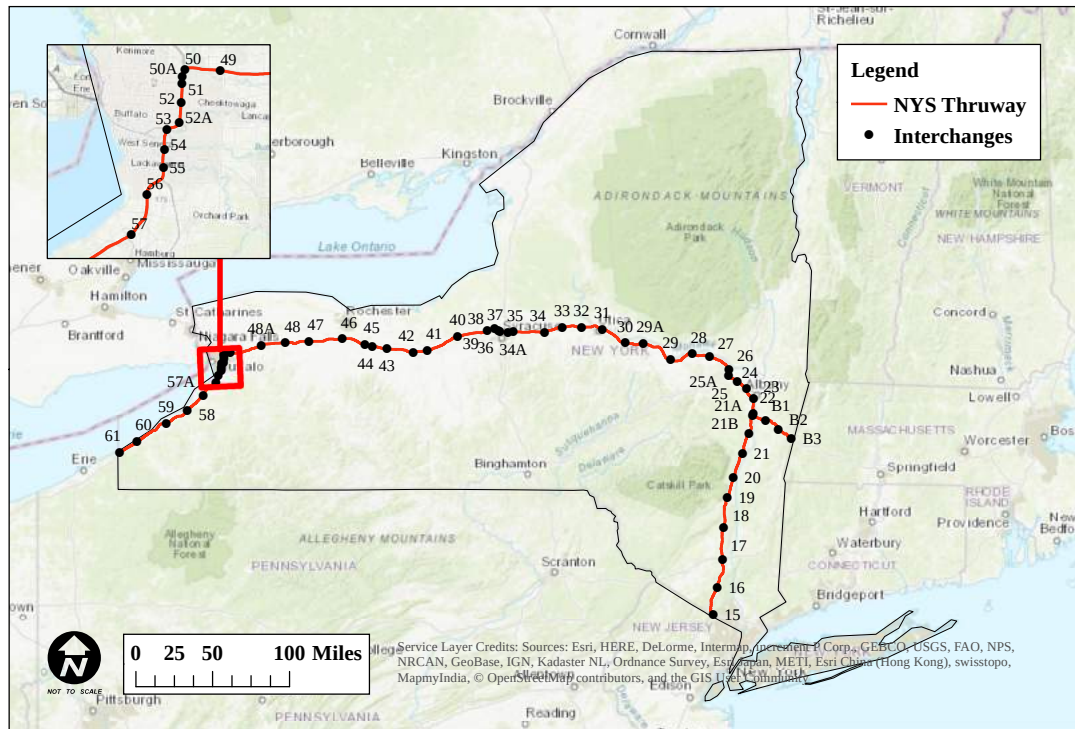


Figure 4.4.: NYS Thruway entrance/exit points. Own illustration created with ArcGIS with data from ArcGIS Online (2015a).

Complementing this figure, Table 4.1 on the following page lists the entrance/exit points of the Thruway.

Table 4.1.: NYS Thruway entrance/exit points (NYSTA, 2016c).

No.	Toll station	No.	Toll station
15	Woodbury	34A	Syracuse (I-481)
16	Harriman - Route 17	35	Syracuse - Route 298
17	Newburgh (I-84) Route 17K	36	Syracuse (I-81)
18	New Paltz - Route 299	37	Electronics Pkwy.
19	Kingston - Route 28	38	Syracuse-Liverpool Route 57
20	Saugerties - Route 32	39	Syracuse (I-690)
21	Catskill - Route 23	40	Weedsport - Route 34
21B	Coxsackie - Route 9W	41	Waterloo - Route 414
	B1 Hudson-Renss.	42	Geneva - Route 14
21A	B2 Taconic Pkwy.	43	Manchester - Route 21
	B3 Canaan (Mass. line)	44	Canandaigua - Route 332
22	Selkirk - Route 396	45	Rochester (I-490)
23	Albany (I-787)	46	Rochester (I-390)
24	Albany (I-87 & I-90)	47	Leroy (I-490)
25	Schenectady (I-890)	48	Batavia - Route 98
25A	Schenectady (I-88)	48A	Pembroke - Route 77
26	Schenectady (I-890)	49	Depew - Route 78
27	Amsterdam - Route 30	50	Williamsville (Buffalo)
28	Fultonville - Route 30A	55	Lackawanna (Buffalo)
29	Canajoharie - Route 10	56	Blasdell - Route 179
29A	Little Falls - Route 169	57	Hamburg - Route 75
30	Herkimer - Route 28	57A	Eden-Angola
31	Utica - Route 8 & 12	58	Silver Creek - Route 438
32	Westmoreland - Rome	59	Dunkirk-Fredonia - Route 60
33	Verona - Rome - Route 365	60	Westfield - Route 394
34	Canastota - Route 13	61	Ripley (Pa. Line)

Tables 4.2 and 4.3 show the travel plazas considered in the current study that are accessible to NB and WB travelers and the ones accessible to EB and SB travelers, respectively.

Table 4.2.: Travel plazas considered in the current study that are accessible to NB and WB travelers (NYSTA, 2016d; Open Data NY, 2015).

Plaza	Mile post	Location description	Route	Direction
Sloatsburg	33	Between: Exit 15A and Exit 16	I-87	NB
Plattekill	65	Between: Exit 17 and Exit 18	I-87	NB
Malden	103	Between: Exit 20 and Exit 21	I-87	NB
New Baltimore	127	Between: Exit 21B and Exit 21A	I-87	NB and SB
Pattersonville	168	Between: Exit 26 and Exit 27	I-90	WB
Iroquois	210	Between: Exit 29 and Exit 29A	I-90	WB
Schuyler	227	Between: Exit 30 and Exit 31	I-90	WB
Chittenango	266	Between: Exit 34 and Exit 34A	I-90	WB
Warners	292	Between: Exit 39 and Exit 40	I-90	WB
Junius Ponds	324	Between: Exit 41 and Exit 42	I-90	WB
Seneca	350	Between: Exit 44 and Exit 45	I-90	WB
Ontario	376	Between: Exit 46 and Exit 47	I-90	WB
Clarence	412	Between: Exit 48A and Exit 49	I-90	WB
Angola	447	Between: Exit 57A and Exit 58	I-90	EB and WB

Table 4.3.: Travel plazas considered in the current study that are accessible to EB and SB travelers (NYSTA, 2016d; Open Data NY, 2015).

Plaza	Mile post	Location description	Route	Direction
Angola	447	Between: Exit 57A and Exit 58	I-90	EB and WB
Pembroke	397	Between: Exit 48A and Exit 48	I-90	EB
Scottsville	366	Between: Exit 47 and Exit 46	I-90	EB
Clifton Springs	337	Between: Exit 43 and Exit 42	I-90	EB
Port Byron	310	Between: Exit 41 and Exit 40	I-90	EB
Dewitt	280	Between: Exit 36 and Exit 35	I-90	EB
Oneida	244	Between: Exit 33 and Exit 32	I-90	EB
Indian Castle	210	Between: Exit 29A and Exit 29	I-90	EB
Mohawk	172	Between: Exit 27 and Exit 26	I-90	EB
Guilderland	153	Between: Exit 25 and Exit 24	I-90	EB
New Baltimore	127	Between: Exit 21B and Exit 21A	I-87	NB and SB
Ulster	96	Between: Exit 20 and Exit 19	I-87	SB
Modena	66	Between: Exit 18 and Exit 17	I-87	SB
Ramapo	33	Between: Exit 16 and Exit 15A	I-87	SB

## 4.4. Data overview

Data for the current work were retrieved from Open Data NY (2017) in the form of a CSV file. The dataset, which is named *NYS Thruway Origin and Destination Points for All Vehicles - 1 Hour Intervals: 2016*, contains 20,743,930 rows (equal to 0.644 gigabytes) of data on the number and types of vehicles that entered through each entrance point with their corresponding exit points for the full year of 2016 (NYSTA, 2016b). Throughout this thesis, this dataset is referred to as the NYS Thruway origin-destination (OD) dataset. It is important to note that the data were limited to the tolled section of the NYS Thruway since the toll barriers act as data collection points. Since sections of the Thruway near Buffalo and New York, on which the travel plaza Ardsley is located, are not tolled, these sections and Ardsley were not covered by the data and led to the spatial restriction discussed in the previous section. Table 4.4 below shows a snippet of the raw dataset utilized in the current work.

Table 4.4.: First five rows of the NYS Thruway OD dataset (Open Data NY, 2017).

Date	Entrance	Exit	Interval beginning time	Vehicle class	Vehicle count	Payment type
01/01/2016	15	17	00	2L	21	CASH
01/01/2016	15	17	01	2L	43	CASH
01/01/2016	15	17	02	2L	50	CASH
01/01/2016	15	17	03	2L	22	CASH
01/01/2016	15	17	04	2L	29	CASH

Referring to the table above, date represents the date on which the transactions occurred, entrance represents the toll plaza through which the vehicles entered, exit represents the toll plaza through which the vehicles exited, interval beginning time represents the beginning hourly interval (0–23), vehicle class represents NYSTA classification of the vehicles, vehicle count represents the number of vehicles reported, and payment type describes whether the customer paid for their trip using “CASH” or “E-ZPass”<sup>[1]</sup> (NYSTA, 2016a). Regarding the fifth column, vehicle class, NYSTA classifies vehicles as shown in the following table.

Table 4.5.: NYSTA vehicle classifications (NYSTA, 2016b).

Vehicle class	Height	Number of axles
2L	Under 7 feet 6 inches	2
3L	Under 7 feet 6 inches	3
4L	Under 7 feet 6 inches	4 or more
2H	7 feet 6 inches or greater	2
3H	7 feet 6 inches or greater	3
4H	7 feet 6 inches or greater	4
5H	7 feet 6 inches or greater	5
6H	7 feet 6 inches or greater	6
7H	7 feet 6 inches or greater	7 or more

<sup>[1]</sup>E-ZPass is an electronic toll collection system used in NYS (NYSTA, 2017c).



## 5. Methodology

The two research questions introduced in Chapter 1 framed the two main tasks of this thesis work: truck parking demand modeling and TPIMS modeling. The method of developing the truck parking demand model of the NYS Thruway is described in the next section, Section 5.1. The TPIMS modeling task is addressed in Section 5.2, which describes the differences between the model setups of the two scenarios: the No-build Scenario and the TPIMS Scenario.

### 5.1. Truck parking demand modeling

This section details the steps followed for developing a truck parking demand model of the NYS Thruway, which was created with the combination of Vissim and a Component Object Model (COM) interface script written in the Python programming language. Information on COM is given in Section 5.1.4.

#### 5.1.1. Initial data analysis

The NYS Thruway OD data were first processed in order to determine a date of interest to focus on for the truck parking demand model and both models associated with the TPIMS modeling task. A Python script that uses the data as input to sum the vehicle count for each day was composed. Figure 5.1 below plots the daily vehicle count on the NYS Thruway over the year 2016.

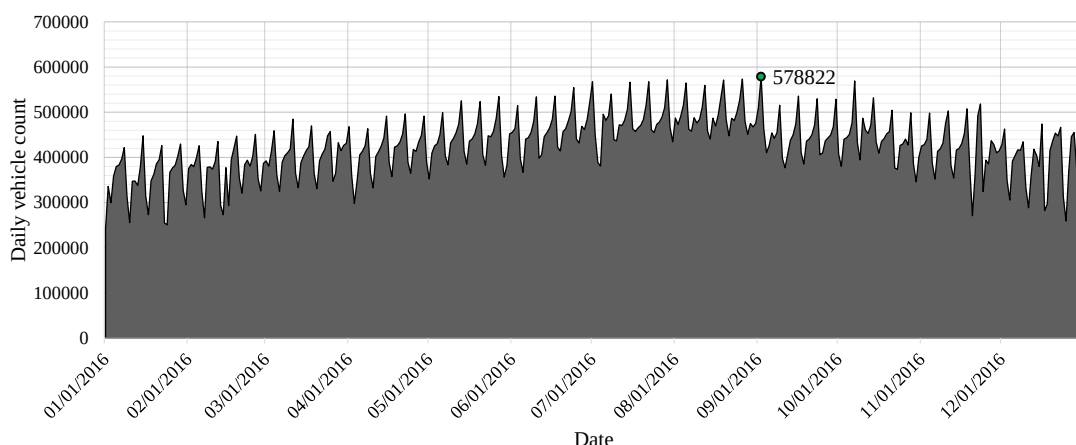


Figure 5.1.: NYS Thruway daily vehicle count for 2016. The labels on the x-axis are in MM/DD/YYYY format.

In this figure, the green dot and data label indicate the day that experienced the most vehicles traveling on the NYS Thruway in 2016, which was Friday, September 2<sup>nd</sup>. On this day, 578,822 vehicles in total traveled on the tolled section of the Thruway. Of this total number, 42,820 were trucks, accounting for 7.4% of the total traffic. The most outstanding feature of traffic patterns over the full year is the trend of high peaks followed by dips. The peaks are typically Fridays, whereas the dips are weekends with Sundays usually having the least traffic. Minor variations are due to bank holidays, e.g. the long weekend of Thanksgiving, which was on Thursday, November 24<sup>th</sup>, 2016. Additionally, an oscillation with a period of one year and an amplitude of roughly 100,000 vehicles per day with peaks during the months July and August can be observed. Supplemental figures that visualize the NYS Thruway OD data are provided in Appendix B.

As mentioned in the previous paragraph, September 2<sup>nd</sup> experienced the most vehicles traveling on the Thruway in 2016. Since studying the Thruway at its peak daily vehicle count makes it highly interesting for truck parking demand modeling and TPIMS modeling, all modeling tasks in the current work were carried out using input data for only this specific day. Although this day experienced the maximum daily vehicle count, the author argues that it still represents a typical Friday during summer and is not a statistical outlier. Thus, it is representative of typical high volume traffic behavior.

### 5.1.2. Vissim model development

A model in Vissim was then developed following the enumerated steps below. These steps describe concepts and introduce terms that are specific to the software. For this section, the reader is assumed to have a basic understanding of Vissim. Otherwise, the user manual provides a sufficient explanation of the software; see PTV AG (2016b). Supplementing this section is Appendix C, which provides screenshots showing how Vissim was configured.

1. **Initial setup:** Vissim was opened, and a new project file was created. All units were changed to imperial in the *Network Settings* window.
2. **Road network modeling:** The built-in background map was activated, and the location of the NYS Thruway was found. Using the background map, links and connectors were added with a relatively high degree of precision for the full network of [number of miles of your resulting network], ensuring that the number of lanes of the links and connectors corresponded to the number of lanes shown on the background map; see Figure 5.2a for the full network modeled in Vissim.
3. **Entrance/exit point modeling:** To model an entrance/exit point (or interchange), a one-lane link was added parallel to each side of the NYS Thruway, making sure that the direction of travel of the link corresponded to the same direction of the Thruway on that side. Connectors were added



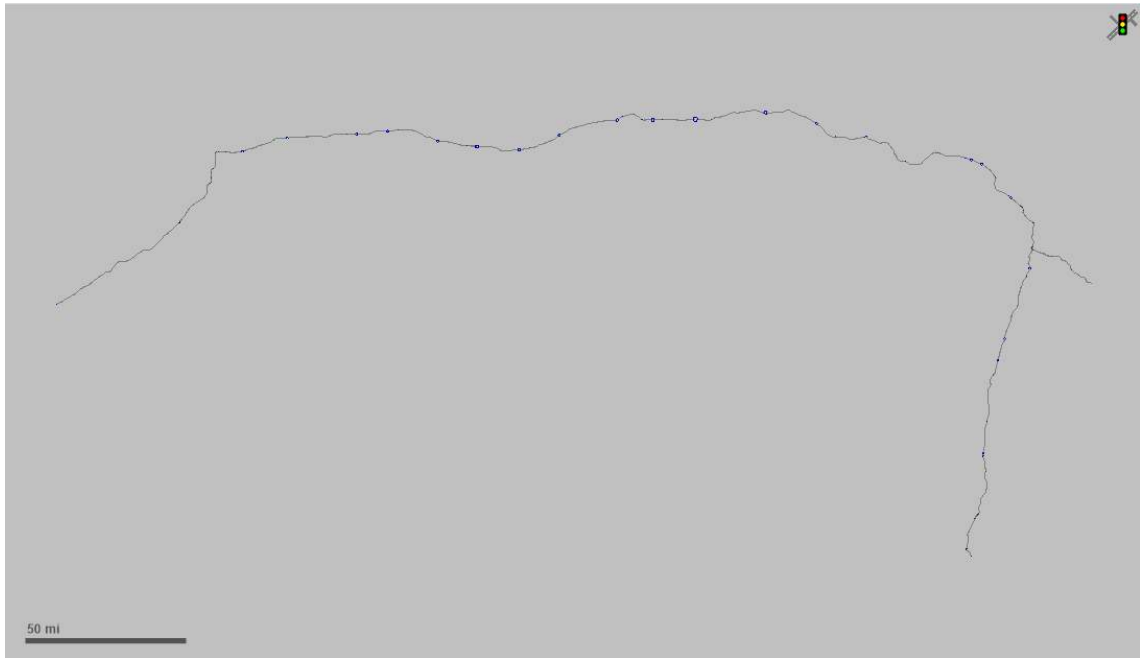
between these one-lane links and the Thruway. Conflict areas were changed to make sure that vehicles entering the Thruway are not be blocked by traffic on the Thruway. Parking lots were added to both one-lane links and were assigned the same unique zone number. This procedure was repeated for all entrance/exit points considered in this study. Figure 5.2b exemplifies how an interchange was modeled in Vissim.

4. **Travel plaza modeling:** Modeling a travel plaza followed a similar approach to modeling an entrance/exit point. A one-lane link was added parallel to the appropriate side of the NYS Thruway, again making sure that the direction of travel of the link corresponded to the same direction of the Thruway on that side. Connectors were added between the one-lane link and the Thruway. Conflict areas were changed to make sure that vehicles entering the Thruway are not be blocked by traffic on the Thruway. A reduced speed area was added on the link representing the travel plaza to slow vehicles to 30 miles per hour (mph). An abstract parking lot was added to this link, was named by the travel plaza it represents, was given a capacity of 1,000 vehicles, and was assigned a zone number of 99. This procedure was repeated for all travel plazas considered in this study. The reason the capacity was set to 1,000 is because only the demand side is focused on in the truck parking demand model. In other words, no limits on parking supply are set since it is of interest to observe where truck drivers would like to park given no restrictions on supply. In fact, the hypothetical capacity of 1,000 was never reached during the simulation. Figure 5.2c exemplifies how a travel plaza was modeled in Vissim.
5. **Vehicle types/vehicle classes:** Four new vehicle types (210, 211, 220, 221) as well as four new vehicle classes (70, 80, 90, 100) were added; see Table 5.1 below for a summary of the vehicles utilized in the Vissim model. Vehicle types 210, 211, 220, and 221 were created based on the existing vehicle type 200. Vehicle type 210 represents a truck searching for short-term parking, and vehicle type 211 represents a truck that is already parked short term. Vehicle type 220 represents a truck searching for long-term parking, and vehicle type 221 represents a truck that is parked long term. In this thesis, short-term and long-term parking were assumed to be 30 minutes and 10 hours, respectively. These time frames were chosen because they are in accordance with the basic HOS rules introduced in Section 2.1. All other rules—e.g. the 60-hour on-duty limit, the 70-hour on-duty limit, and the 34-hour restart—could not be modeled in this one-day simulation and are therefore negligible.

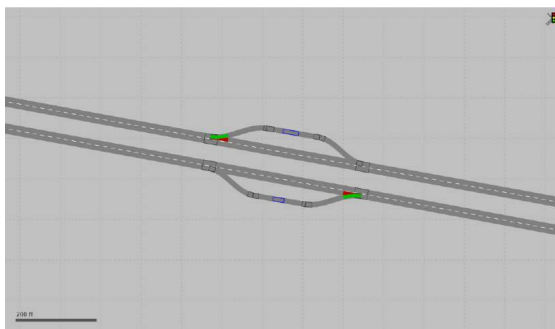
Table 5.1.: Vissim vehicle classifications.

Vehicle type	Vehicle class	Category	Name
100	10	Car	Car
200	20	HGV	Truck
210	70	HGV	Truck searching for short-term parking
211	80	HGV	Truck parked short term
220	90	HGV	Truck searching for long-term parking
221	100	HGV	Truck parked long term

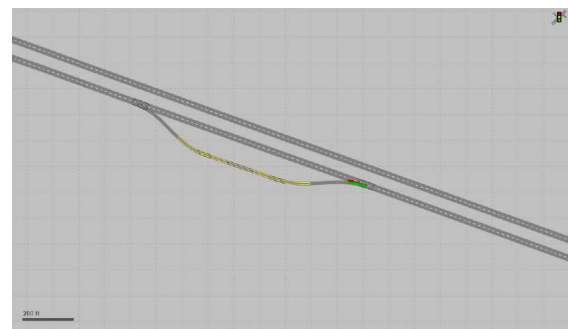
6. ***Desired speed distributions/vehicle compositions:*** Two desired speed distributions were created: *NYS Thruway: Car* and *NYS Thruway: Truck*. *NYS Thruway: Car* was given lower and upper bounds of 55 mph and 75 mph, respectively, whereas *NYS Thruway: Truck* was given lower and upper bounds of 55 mph and 65 mph, respectively. The author argues that these assumed bounds well represent the speed distributions of cars and trucks driving on the NYS Thruway. However, to validate these bounds, empirical observations are needed to adjust the calibration, which was out of scope of this thesis. On the *Vehicle Compositions/Relative Flows* list, *NYS Thruway* was added to the list of vehicle compositions. Vehicle type 100 was added to this composition and was assigned the desired speed distribution *NYS Thruway: Car*, and vehicle types 200, 210, 211, 220, and 221 were added and were assigned the desired speed distribution *NYS Thruway: Truck*.
7. ***Dynamic assignment parameters:*** The dynamic assignment parameters were changed so that a trip chain file was used to input vehicles into the network.
8. ***Dynamic vehicle routing:*** Dynamic vehicle routing decisions, which in Vissim are represented as magenta lines on links, were added upstream of every travel plaza in the model. They were configured to redirect vehicle types 210 and 220 to the next downstream travel plaza, specifically to its abstract parking lot.
9. ***Simulation parameters:*** In the *Simulation Parameters* window, the simulation period was changed to 86,400 simulation seconds, which is equal to one full day. To speed up the simulation run time, the simulation resolution was decreased from the default value of 10 to 1 time step per simulation second, noting that this loss of accuracy is negligible for this study.



(a) Full Vissim network.



(b) Example entrance/exit point.



(c) Example travel plaza.

Figure 5.2.: Full Vissim network, entrance/exit point, and travel plaza.

### 5.1.3. Trip chain file generation

Following the development of the Vissim model, a trip chain file was generated for September 2<sup>nd</sup>, 2016. Traffic demand for dynamic assignment in Vissim is modeled with either OD matrices or a trip chain file, which has a file extension of .fkt (PTV AG, 2016b). An advantage of a trip chain file over an OD matrix is that it offers more detail with respect to the trips of individual vehicles that are placed in a network during a simulation run, which is the reason that the current work implemented it instead of OD matrices. In order to understand how the file is organized, a snippet of an exemplary trip chain file is shown directly below.

```

1.1
1001;100;15;1604;17;101;1800;0;18;102;36000;0;19;103;0
1002;200;15;1433;17;101;1800;0;18;102;36000;0;19;103;0
1003;100;15;2820;17;101;1800;0;18;102;36000;0;19;103;0
1004;200;15;1529;17;101;1800;0;18;102;36000;0;19;103;0
1005;100;15;3494;17;101;1800;0;18;102;36000;0;19;103;0

```

Figure 5.3.: Snippet of example trip chain file.

The first row indicates the data format version number of the trip chain file, which can either be 1.1 as shown or 2.1. The main difference between the two data format versions is that 2.1 uses world coordinates to indicate the destination of a vehicle rather than a zone number. As discussed in the previous section, the Vissim model was developed using zones that represent the highway entrance/exit points; thus, this thesis work used data format version 1.1 as it was more applicable to the way the model was setup in Vissim.

Focusing on the remaining rows of the trip chain file snippet above, there are several entries separated by semicolons. From left to right, the entries represent the vehicle number, type of vehicle, origin zone number, departure time (in seconds), destination zone number, activity number of the first trip, and minimum dwell time of the first trip (in seconds). The vehicle number is a unique identifier for a vehicle in the network. The origin zone number is the zone from which a vehicle enters the network. The departure time represents when a vehicle first appears in the network. The destination zone number is the destination of the first trip. The activity number of the first trip is a user-defined number that labels the trip; here, 101 was chosen based on an example in the Vissim user manual. The minimum dwell time of the first trip represents how many seconds a vehicle remains in the destination zone before departing for its second trip. The next entry in the trip chain file is the departure time of the second trip; here it is 0, which means that the vehicle will depart for the second trip as soon as it remains in the destination zone for the minimum dwell time. The following three entries are the destination zone number of the second trip, activity number of the second trip, and minimum dwell time of the second trip. The last four entries are the departure time, destination zone number, activity number, and minimum dwell time, all of the third trip. Trip chain files can be easily extended to include additional trips.

For the current work, a Python script that uses the NYS Thruway OD data as input to generate a trip chain file for one full day was developed. Within the script, it is possible to adjust the date to any day in 2016. The script converts NYSTA vehicle classifications presented in Table 4.5 to Vissim vehicle classifications. All

vehicles belonging to NYSTA vehicle class 2L, 3L, 4L, 2H, and 3H are converted to cars (or Vissim vehicle type 100), whereas vehicles belonging to NYSTA vehicle class 4H, 5H, 5S, 6H, 6S, 7H, and 7S are converted to trucks (or Vissim vehicle type 200). The departure time of a vehicle was calculated by taking its interval beginning time, converting it into seconds, and adding a random value between 0 and 3,600 seconds, assuming a uniform distribution of entry times over the full hour.

Figure 5.4 below shows the first seven rows of the generated trip chain file for September 2<sup>nd</sup>, 2016. All vehicles that entered the considered sections of the Thruway on this date are represented in this file, even if they entered shortly before the end of the day.

```
1.1
1000;200;99;1;60;101;0
1001;100;15;1604;17;101;1800;0;17;102;36000;0;17;103;0
1002;100;15;1433;17;101;1800;0;17;102;36000;0;17;103;0
1003;200;15;2820;17;101;1800;0;17;102;36000;0;17;103;0
1004;100;15;1529;17;101;1800;0;17;102;36000;0;17;103;0
1005;100;15;3494;17;101;1800;0;17;102;36000;0;17;103;0
```

Figure 5.4.: Snippet of trip chain file used in the current study.

To address an issue with Vissim, the second row was manually added after the trip chain file was generated. This row shows the trip of a truck, whose vehicle number is 1000, origin zone number is 99, entry time is 1 second, and destination zone is 60. As previously mentioned, zone number 99 was assigned to all the abstract parking lots that represent travel plazas. Due to the fact that all vehicles enter the network at entrance/exit points and not at travel plazas, no vehicle in the generated trip chain file had an origin zone of 99. The aforementioned issue was that trucks could not be directed towards this zone without at least one vehicle having an origin zone of 99 for a reason unknown to the author. Thus, this row was added to resolve this issue, which consequently adds one additional truck to the network.

Still referring back to Figure 5.4, the remaining vehicles listed in the file each have a trip chain consisting of three trips with repeating destination zone numbers. This setup constitutes the core modeling feature, i.e. the ability of the trucks in the network to perform both short and long-term parking. As mentioned, the destination zone number represents the destination entrance/exit point on the Thruway.

For the models developed in this thesis work, all trucks were assumed to follow the same schedule for their HOS. If a truck exceeds a total driving time of 7 hours and 30 minutes while in the network, it then searches for short-term parking. After parking for 30 minutes (1,800 seconds), it continues driving towards its destination. If the truck exceeds a total driving time of 10 hours and 30 minutes, it searches for long-term parking and parks for 10 hours (36,000 seconds). The author again emphasizes that this is an assumption, which is that trucks are given 30 minutes to find parking before they violate HOS regulations. Further empirical analyses are required to enhance the model, e.g. applying different HOS schedules. This could be done in a more detailed study but is outside the scope of this thesis.

When a vehicle in Vissim is redirected with a dynamic vehicle routing decision, its destination zone is updated, which in this case is to zone number 99. After parking for the specified minimum dwell time assigned for that trip, the vehicle continues driving towards the destination associated with the next trip in the trip chain. The setup of this trip chain file is flexible, taking into consideration the trucks that enter and leave the network without parking, the trucks that only park short term, and the trucks that park short and then long term.

What should be pointed out is the fact that the current work used a trip chain file for just the full day of September 2<sup>nd</sup>, 2016. No vehicles from the previous day are considered and thus are not included in the trip chain file. This means that the network, the section of the NYS Thruway modeled in Vissim, does not contain any vehicles at the start of a simulation. Consequently, time is required until the simulation reaches a realistic steady state. Thus, focus is placed on the time period of 08:00:00 to the final time at which the simulation outputs values, which is 23:59:50. 08:00:00 was chosen because around this time trucks begin to search for short-term parking, but it should be noted that even from 08:00:00 to 12:00:00 steady-state conditions are most likely not reached. Since there is no carryover of trucks from the previous day, i.e trucks driving or occupying parking spaces, the models require a so called burn-in period of at least of 12 hours in light of the HOS regulations. Explicit case studies that seek to find estimates for parking demand need to address this by conducting a multi-day analysis.

#### **5.1.4. Component Object Model interface script development**

A COM interface script was developed in Python. Its main function is to change the vehicle types of trucks in the network based on their total driving times and if they already parked for a short or long term. The script checks the total driving time of each truck, and if the truck exceeds the chosen HOS thresholds stated in the previous section, it forces the truck to search for parking. A brief overview of COM is provided in the following paragraph.

According to PTV AG (2016a), binary components of different programs collaborate through COM, which provides access to data and functions in other programs. The COM interface allows data contained in Vissim to be accessed and is automatically installed with the full version of the software (PTV AG, 2016a). COM Objects, which in the context of this thesis are certain Vissim objects, can be influenced or read through the COM interface using “a wide range of programming and scripting languages, including VBA, VBS, Python, C, C++, C#, Delphi and MATLAB” (PTV AG, 2016a, p. 8). Thus, within certain limits, it is possible to extend the built-in features of Vissim through the COM interface.

For the model deployed in the current work, it is paramount to understand the COM interaction with Vissim at a fundamental level; therefore, the COM interface script is briefly described in the following paragraph. The COM interface script itself is not provided in this thesis but is available upon request to the author.

When the Python script is run, it loads the necessary dependencies and opens the Vissim project file of the Thruway. It then defines certain simulation parameters, e.g. the simulation end time of 86,400 simulation seconds (or 1 simulation day). Next, it initiates a for loop, which pauses the simulation every 10 simulation seconds, i.e. the time step of the simulation equals 10 seconds. Within this loop, all trucks—vehicle types 200, 210, 211, 220, and 221 in that order—are checked, and if certain criteria are fulfilled, their vehicle types are changed. Following descriptions of selected Vissim vehicle attributes in Table 5.2, the subsequent list elucidates what is checked for each vehicle type and the criteria for changing them.

Table 5.2.: Vissim vehicle attributes used in the current study.

Identifier	Long name	Description
No	Number	Number of the vehicle
VehType	Vehicle type	Vehicle type of the vehicle
StartTm	Start time	Network entry time <sup>[1]</sup>
TmInNetTot	Total time in network	Time the vehicle is in the network <sup>[1]</sup>
OrigZone	Origin zone	Number of the origin zone
ParkState	Parking state	Binary value <sup>[2]</sup>

<sup>[1]</sup> In units of simulation seconds

<sup>[2]</sup> 1 for parked, 0 for not parked

- **Vehicle type 200:** The following attributes of all trucks of type 200 are read: No, VehType, StartTm, TmInNetTot, and OrigZone. If a truck has a total driving time greater than 37,800 seconds (10 hours and 30 minutes), then its vehicle type is changed to 220. If a truck has a total driving time greater than 27,000 seconds (7 hours and 30 minutes) and its start time (or network entry time) is before 16:00, then its vehicle type is changed to 210. Trucks are no longer changed to vehicle type 210 if they enter the network after 16:00, and this is based on the argument that they have driven long enough and already parked for a short term. This assumption is reflected in the trip chain file. In this file, the first dwell time value for trucks entering after 16:00 is 36,000 seconds (or 10 hours) instead of 1,800 seconds (or 30 minutes).
- **Vehicle type 210:** The following attributes of all trucks of type 210 are read: No, VehType, StartTm, TmInNetTot, and ParkState. The total driving time of every truck of vehicle type 210 is recorded, and if a truck has ParkState = 1, then its vehicle type is changed to 211.
- **Vehicle type 211:** The following attributes of all trucks of type 211 are read: No, VehType, and ParkState. If a truck of type 211 has ParkState = 0, then its vehicle type is changed to 200.
- **Vehicle type 220:** The following attributes of all trucks of type 220 are read: No, VehType, StartTm, TmInNetTot, and ParkState. The total driving time of every truck of vehicle type 220 is recorded, and if a truck has ParkState = 1, then its vehicle type is changed to 221. Important to mention is that any previous short-term parking is taken into account and is not considered as driving time.
- **Vehicle type 221:** The following attributes of all trucks of type 221 are read: No, VehType, and ParkState. If a truck of type 221 has ParkState = 0, then its vehicle type is changed to 200.

Within the aforementioned for loop, the total driving time of each truck in the network is checked. In reality, before a truck enters the NYS Thruway, the driver has been on-duty and driving for a certain amount of time. Due to data limitations and the sheer effort required to ascertain or accurately approximate the pre-network driving times of all trucks, the pre-network driving time of each truck was calculated by

$$t_{pre-network\ driving} = 0.75 \times t_{start} \times R, \quad (5.1)$$

where  $t_{pre-network\ driving}$  is the pre-network driving time of the vehicle in simulation seconds,  $t_{start}$  is the start time of the vehicle (or, to be more precise, when the vehicle entered the network) in simulation seconds, and  $R$  is a uniformly distributed random variable between 0 and 1 assigned to the truck at the start



of the script. The pre-network driving time is assumed to be proportional to the network entry time of the vehicle. Since a value was necessary to reduce pre-network driving times, an iterative approach was taken to test numbers between 0 and 1, and 0.75 was found to be a reasonable assumption based on the simulation results.

Equation 5.1 was assumed for the purposes of this work, but either it needs to be calibrated or more information about the pre-network driving times of trucks needs to be gathered. The pre-network driving times may not be completely realistic; however, if they are not considered, all trucks would enter the Thruway with a total driving time of 0. The author argues that this would yield a less realistic model than assuming pre-network driving times based on the equation above. This also incorporates randomness, which is arguably a benefit.

Using the result of Equation 5.1 as an input, the total driving time for each truck is then calculated by

$$t_{total\ driving} = t_{in-network\ driving} + t_{pre-network\ driving}, \quad (5.2)$$

where  $t_{total\ driving}$  is the total driving time of the vehicle in simulation seconds and  $t_{in-network\ driving}$  is the in-network driving time of the vehicle derived from the Vissim vehicle attribute TmInNetTot. Note that the in-network driving time does not include parking duration.

Referring back to the COM interface script, the driving times of vehicle types 210 and 220 by vehicle number are recorded, which was done to determine the number of trucks that violate HOS regulations in the post-modeling analysis. Moreover, the abstract parking lots that represent travel plazas are then checked at each iteration of the for loop. The occupancy of every parking lot is recorded in a separate CSV file. Once all iterations of the for loop are completed, the Vissim project file is closed.

## 5.2. Truck parking information management system modeling

Using the combination of Vissim and a COM interface script written in the Python programming language, two scenarios were modeled to address the second research question of this thesis. The two scenarios are the No-build Scenario, which models the existing situation in terms of truck parking supply and demand, and the TPIMS Scenario. This section details the steps followed for modeling the two scenarios.

### **5.2.1. Description of scenarios**

As previously mentioned, the No-build Scenario models the existing situation in terms of truck parking supply and demand. In this scenario, all travel plazas have both a set number of legal truck parking spaces as well as an assumed number of illegal truck parking spaces; see Table 5.3. Thus, the total number of truck parking spaces is equal to the sum of legal and illegal spaces. The number of legal truck parking spaces at each travel plaza was counted using aerial imagery, whereas the number of illegal truck parking spaces was calculated by simply multiplying the number of legal truck parking spaces by an assumed value of 50%. This is simply a heuristic assumption for the purpose of this thesis; however, again, empirical data is needed to get more accurate estimates of the number of illegal truck parking spaces at each travel plaza. An HOS violation can occur if both the legal and illegal parking capacities are reached. In this situation, trucks still enter the travel plaza and wait until a parking space becomes available, where the waiting time is counted towards the driving time.

The TPIMS Scenario models the NYS Thruway with VMSs—to remind the reader, variable message signs—upstream of every travel plaza. These signs provide truck drivers with information on the available number of truck parking spaces. In the model, truck drivers receive this parking availability information of a travel plaza once they directly approach it. Truck operators do not have this information for other travel plazas downstream, e.g. the second next one. In the TPIMS Scenario, the number of illegal truck parking spaces is zero for all travel plazas, so truck operators are assumed to never park illegally, but as a consequence, they may exceed their legal HOS in contrast to the No-build Scenario. The model does not take into account truck parking reservations, and all truck operators were assumed to use this information. How this was done in Vissim is discussed in the following section.

In both scenarios, an HOS violation occurs when a truck searching for short-term parking (vehicle type 210) exceeds 8 hours of driving time or when a truck searching for long-term parking (vehicle type 220) exceeds 11 hours of driving time.

Table 5.3.: Number of truck parking spaces by travel plaza.

Travel plaza	Number of legal truck parking spaces	Number of illegal truck parking spaces	Total number of truck parking spaces
Angola (EB direction)	40	20	60
Angola (WB direction)	24	12	36
Chittenango	32	16	48
Clarence	32	16	48
Clifton Springs	25	13	38
Dewitt	23	12	35
Guilderland	50	25	75
Indian Castle	30	15	45
Iroquois	30	15	45
Junius Ponds	43	22	65
Malden	42	21	63
Modena	21	11	32
Mohawk	16	8	24
New Baltimore	40	20	60
Oneida	27	14	41
Ontario	34	17	51
Pattersonville	52	26	78
Pembroke	40	20	60
Plattekill	22	11	33
Port Byron	22	11	33
Ramapo	20	10	30
Schuyler	20	10	30
Scottsville	37	19	56
Seneca	40	20	60
Sloatsburg	40	20	60
Ulster	42	21	63
Warners	35	18	53

### 5.2.2. Vissim model adjustment

The models of the two scenarios were for the most part based on the same Vissim project file used for the truck parking demand modeling task, whose development is described above in Section 5.1.2. Only minor changes were made. For the No-build Scenario, the capacity of each travel plaza was changed from 1,000 to the total number of legal and illegal truck parking spaces, shown in the fourth column of Table 5.3 above, whereas for the TPIMS Scenario, the capacity of each travel plaza was adjusted to the number of legal truck parking spaces, shown in the second column of the table.

Another change made to the Vissim project file for the TPIMS Scenario was that an additional dynamic vehicle routing decision was added upstream of every travel plaza in the model, but placed downstream of the existing dynamic vehicle routing decision; see the bottom right-hand corner of Figure 5.5, which shows two dynamic vehicle routing decisions.<sup>[3]</sup> As previously described, the existing dynamic vehicle routing decision directs vehicle types 210 and 220 to-

<sup>[3]</sup>A dynamic vehicle routing decision is represented in Vissim as a magenta line on a link.

wards travel plazas. The purpose of the second dynamic vehicle routing decision is to redirect vehicle types 210 and 220 to the next travel plaza on their routes if there is no available parking at the immediate travel plaza. Without the additional dynamic vehicle routing decision—so in the No-build Scenario—trucks are directed towards the travel plaza, but if the parking lot is full, the trucks wait in front of the parking lot until a space becomes available. As mentioned above, the COM interface script records the driving times of vehicle types 210 and 220 by vehicle number, i.e. the waiting time still counts towards the driving time. Thus, the trucks that are redirected towards a full parking lot in the No-build Scenario might violate HOS regulations waiting for a parking space to become available.

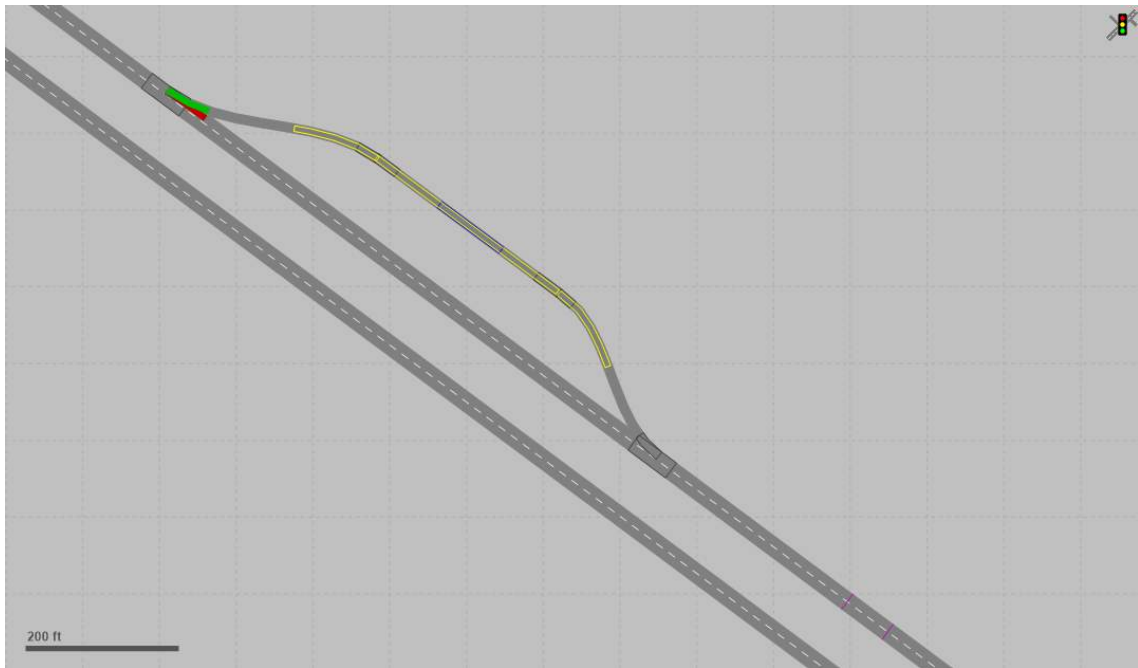


Figure 5.5.: TPIMS Scenario example travel plaza.

### 5.2.3. Component Object Model interface script adjustment

For the TPIMS modeling task, the same COM interface script used for the truck parking demand modeling task was applied. Therefore, the only changes made for this task were done in the Vissim project file and not in the Python script.

### 5.2.4. Summary

The purpose of this thesis is neither to provide highly accurate estimates of truck parking demand nor to conduct an overly thorough scenario analysis of a TPIMS on the NYS Thruway, but rather is meant to demonstrate the general methodology of how Vissim may be used to perform such an in-depth study. All numbers reported herein should be considered carefully, and focus should be placed on the time period from 08:00:00 to 23:59:50. With the assumptions

described in this chapter, approximating potentially realistic behavior was an aim of this work. However, case studies require more empirical input to calibrate and validate the truck parking demand model and the TPIMS model. For a summary of the model assumptions, see Table 5.4 below. Assumptions are presented in the table in the same order as they were introduced and discussed in this chapter.

Table 5.4.: Summary of model assumptions.

Assumption	Description
Parking duration	Short-term parking was assumed to be 30 minutes, whereas long-term parking was assumed to be 10 hours.
Desired speed distributions	<i>NYS Thruway: Car</i> was assigned a lower bound of 55 mph and an upper bounds of 75 mph, whereas <i>NYS Thruway: Truck</i> was assigned a lower bound of 55 mph and an upper bound of 65 mph.
Vehicle departure time	The departure time of a vehicle was calculated by taking its interval beginning time, converting it into seconds, and adding a random value between 0 and 3,600 seconds, assuming a uniform distribution of entry times over the full hour.
HOS schedules	All trucks were assumed to follow the same schedule for their HOS. If a truck exceeds a total driving time of 7 hours and 30 minutes while in the network, it then searches for short-term parking. After parking for 30 minutes (1,800 seconds), it continues driving towards its destination. If the truck exceeds a total driving time of 10 hours and 30 minutes, it searches for long-term parking and parks for 10 hours (36,000 seconds).
Late day parking search	Trucks were no longer changed to vehicle type 210 if they enter the network after 16:00.
Pre-network driving time	The pre-network driving time was assumed to be proportional to the network entry time of the vehicle.
Legal and illegal parking	All travel plazas were assigned a set number of legal truck parking spaces as well as an assumed number of illegal truck parking spaces.

## 6. Results and Discussion

This chapter presents the results of the current work. After three simulations were run, one for the truck parking demand model and one for each of the two scenarios belonging to the TPIMS modeling task, the output data were brought into Microsoft Excel for data processing and visualization. Following a discussion of the results of the truck parking demand modeling task in Section 6.1, the results of the TPIMS modeling task are presented and discussed in Section 6.2. Augmenting this chapter is Appendix D, which provides supplemental figures that report the results of the truck parking demand model and both models associated with the TPIMS modeling task.

### 6.1. Truck parking demand modeling

For the truck parking demand model, determining the development of truck parking demand throughout the day is of interest. In Figure 6.1 below, the truck parking demand is shown for the travel plaza Angola (EB direction) on September 2<sup>nd</sup>, 2016, from 08:00:00 to 23:59:50. This travel plaza was chosen since it experienced the greatest truck parking demand out of all the travel plazas considered in this study, which provides an interesting example for discussion.

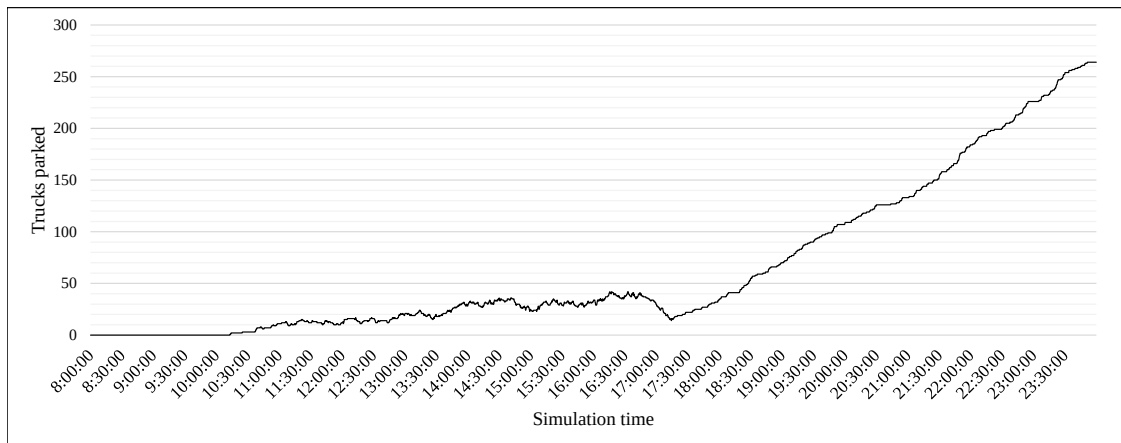


Figure 6.1.: Angola travel plaza (EB direction): Truck parking demand over day.

The demand remains at 0 until approximately 10:00:00, after which trucks searching for short-term parking enter the travel plaza and rest for 30 minutes. After around 17:30:00, there is a nearly linear rapid increase in the number of trucks parked, surpassing 250 near the end of the simulation run.

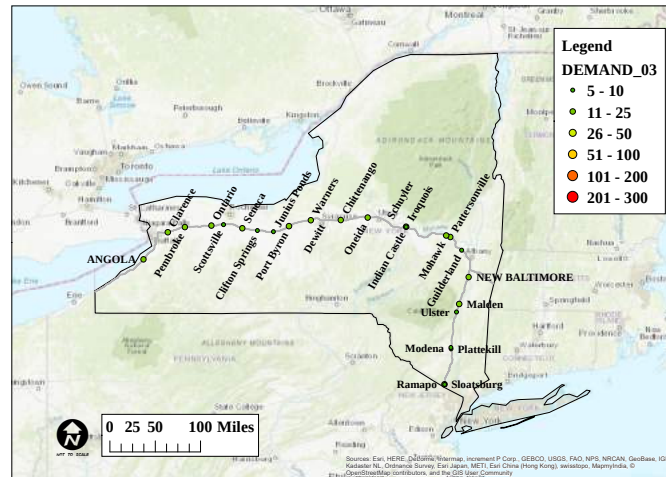
The previous discussion acts as a good example of how truck parking demand can be quantified for the course of a day at a single travel plaza. Interpretation for the truck parking demand of all other travel plazas is analogous. All figures for each single travel plaza are provided in Appendix D.

With these data, the maximum truck parking demand was calculated for every travel plaza within different time periods on September 2<sup>nd</sup>, 2016; see Table 6.1 below. A color scale is applied to the table to highlight high and extreme values, shown in orange and red, respectively. *High* is defined by the author as above 100 trucks within a time period, whereas *extreme* is defined as above 200.

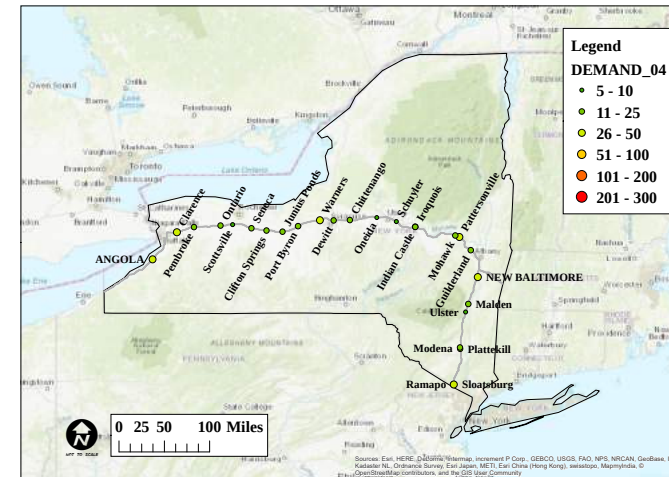
Table 6.1.: Maximum truck parking demand.

Travel plaza	Parking demand 08:00:00 – 11:59:50	Parking demand 12:00:00 – 15:59:50	Parking demand 16:00:00 – 19:59:50	Parking demand 20:00:00 – 23:59:50
Angola (EB)	15	36	107	264
Angola (WB)	10	35	41	196
Chittenango	20	19	51	94
Clarence	19	28	31	190
Clifton Springs	10	15	42	83
Dewitt	4	13	29	41
Guilderland	8	21	29	84
Indian Castle	6	15	20	32
Iroquois	11	15	29	59
Junius Ponds	9	12	33	61
Malden	12	14	17	29
Modena	9	12	18	28
Mohawk	11	13	30	51
New Baltimore	18	32	68	155
Oneida	12	10	23	42
Ontario	12	16	37	83
Pattersonville	14	29	54	198
Pembroke	12	24	35	67
Plattekill	8	18	58	153
Port Byron	11	16	30	50
Ramapo	14	18	42	96
Schuyler	4	6	9	17
Scottsville	6	7	12	22
Seneca	12	16	37	136
Sloatsburg	10	41	106	210
Ulster	10	10	18	34
Warners	20	28	70	144

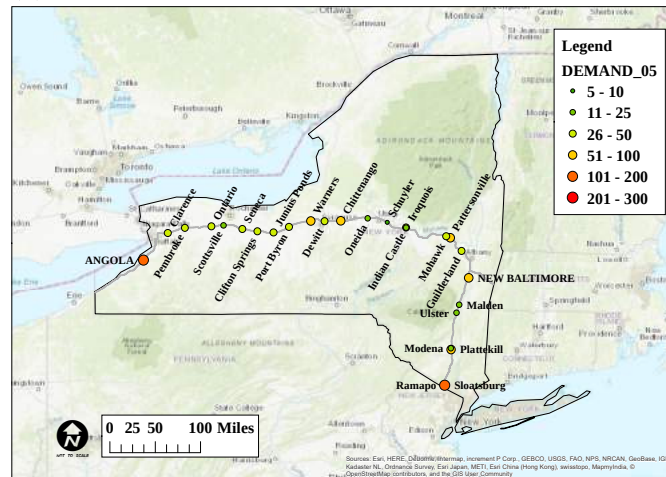
Complementing this table is Figure 6.2 on the following page, which includes four subfigures each visualizing the extent of the truck parking demand of every travel plaza for a different time period.



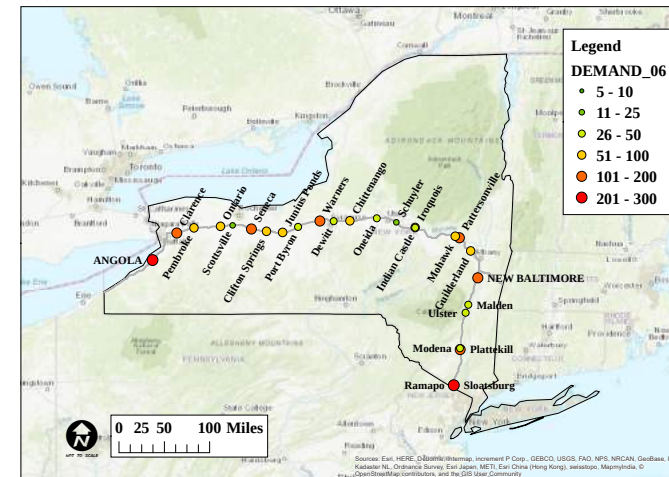
(a) From 08:00:00 – 11:59:50.



(b) From 12:00:00 – 15:59:50.



(c) From 16:00:00 – 19:59:50.



(d) From 20:00:00 – 23:59:50.

Figure 6.2.: Maximum truck parking demand.



The starting time for the parking demand analyses in all previous figures and tables was chosen to be 08:00:00. By design of this one-day simulation, there is no truck parking demand during the period of 00:00:00 to 07:59:00, which is most likely unrealistic and presumably leads to an underestimation of parking demand in the first hours of the day. Due to the assumption made that every truck follows the same schedule for their HOS in addition to the trip chain file only including the vehicles for September 2<sup>nd</sup>, 2016, the network does not contain any trucks at the start of a simulation that are interested in parking. This restriction of the model to just one day results in a model that considers only trucks entering that very day, i.e. trucks with an older driving history are ignored.

As mentioned above, a multi-day analysis could be conducted in future research to address the carryover of trucks that are already parked or have driven long time. A different approach to modeling the HOS schedules of the truck drivers could also be taken to initiate parking demand earlier in a simulation. This would result in the more realistic situation of travel plazas being occupied during the early hours of a day.

Although there are the aforementioned setup time limitations with this truck parking demand model, the author argues that the parking demand converges to a long-term steady state over the course of the second half of the day and, thus, still provides insight into which travel plazas could be renovated to include more truck parking. Furthermore, these results illustrate that there is potential for a TPIMS to distribute parking demand throughout the highway system. First, the travel plazas Angola (EB direction) and Sloatsburg experience extreme truck parking demand at night (from 20:00:00 to 23:59:50). Angola (WB direction), Clarence, New Baltimore, Pattersonville, Plattekill, Seneca, and Warners see high truck parking demand during the same time period. Thus, after taking into consideration current parking supply these travel plazas should be further investigated to see if it is reasonable to add more truck parking spaces. Second, looking at the demands of every travel plaza for each time period, it can be observed that not all the travel plazas experience the same level of demand, indicating that there is a potential for a TPIMS to distribute demand among the different travel plazas. In theory, this would decrease the demand of the travel plazas that experience high parking demand and would increase the demand of those that experience low parking demand.

It should be emphasized that the numbers reported in this section are based on September 2<sup>nd</sup>, 2016, which experienced the most vehicles traveling on the NYS Thruway in 2016. Therefore, the reported numbers for truck parking demand should be understood as upper bounds. The travel plazas that experienced high or extreme truck parking demand could get relief by the other travel plazas via a TPIMS.

## 6.2. Truck parking information management system modeling

For the TPIMS modeling task, comparing the two scenarios—the No-build Scenario and the TPIMS Scenario—is of interest. Figures 6.3, 6.4, and 6.5 below show the results of the TPIMS modeling scenario analysis for the travel plazas Malden, Schuyler, and Sloatsburg, respectively. These three travel plazas were selected because the results demonstrate two different outcomes of implementing a TPIMS: either an increase (Malden and Schuyler) or a decrease (Sloatsburg) in the number of trucks parked at the facility. Table 6.1 in the previous section shows that Malden has a relatively low truck parking demand throughout the day, Schuyler has the lowest demand from 20:00:00 to 23:59:50, and Sloatsburg has the second highest demand during this time period.

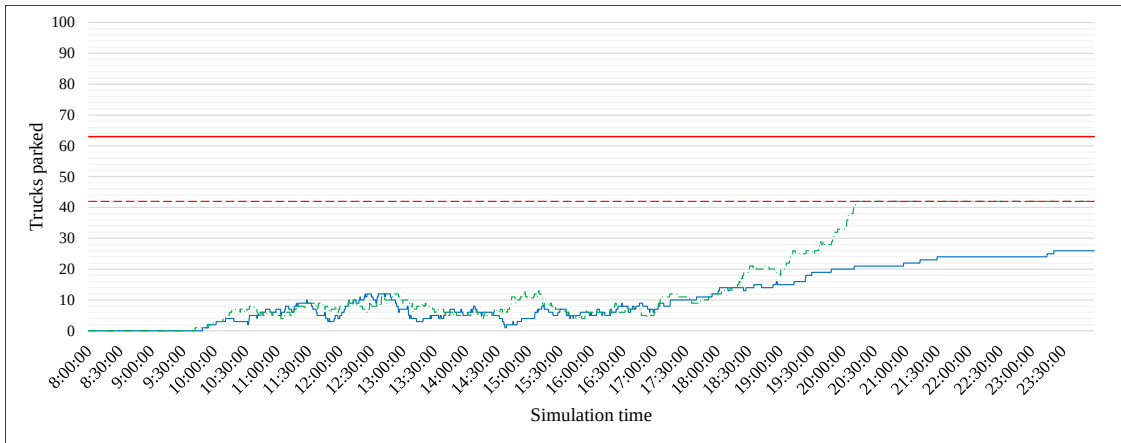


Figure 6.3.: Malden travel plaza: TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario; the dash-dot green line represents the TPIMS Scenario.

Based on the development of truck parking demand for the two scenarios in Figure 6.3, a substantial difference between the No-build Scenario and the TPIMS Scenario can be observed. In the No-build Scenario, the truck parking demand for this day never reaches the legal capacity of the travel plaza. However, in the TPIMS Scenario, the legal capacity is reached at around 20:00:00. Upstream of Malden is first Plattekill and then Sloatsburg, which experienced high and extreme truck parking demand, respectively; see Table 6.1 in the previous section. These results indicate that the TPIMS is distributing parking demand throughout the Thruway system, redirecting trucks searching for parking from high demand travel plazas to low demand ones.

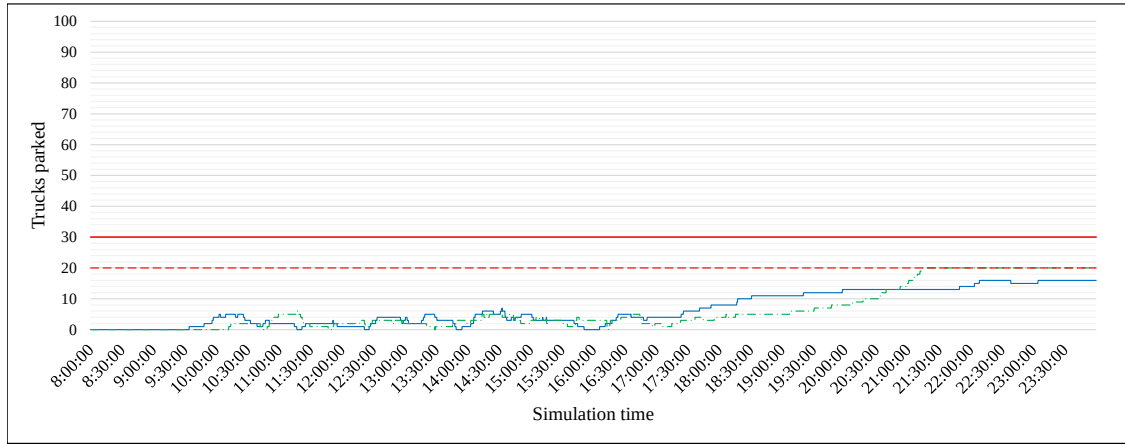


Figure 6.4.: Schuyler travel plaza: TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario; the dash-dot green line represents the TPIMS Scenario.

Looking at Figure 6.4, a similar behavior as discussed in the previous paragraph can be seen, again pointing to the fact that the TPIMS might be distributing parking demand. However, one key difference between this figure and the previous one is that the demand is generally lower before 20:30:00, and then it increases after 20:30:00, meaning that travel plazas of this kind play different roles at different times.

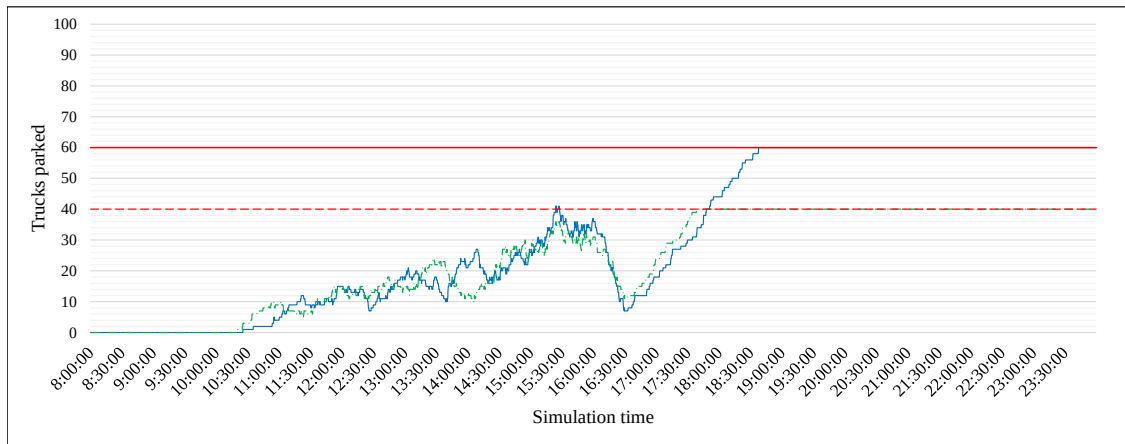


Figure 6.5.: Sloatsburg travel plaza: TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario; the dash-dot green line represents the TPIMS Scenario.

Comparing the two scenarios in Figure 6.5, the results show that the development of the number of trucks parked in the No-build Scenario closely follows

that of the TPIMS Scenario. The major difference is that near the end of the day (around 17:30:00), the number of trucks parked reaches the legal parking capacity in the TPIMS Scenario, whereas for the No-build Scenario, this number exceeds this threshold and reaches the maximum truck parking capacity (legal and illegal parking spaces). This indicates that in the TPIMS Scenario trucks searching for parking are redirected to the next downstream travel plaza (Plattekil) starting at approximately 17:30:00; see Appendix D.

An outstanding feature that can be seen in this figure is the behavior starting at around 16:00:00, after which there is a sudden drop in parking demand. This can be explained by the fact that until this time there are mainly trucks that are parked for a short term. Due to the assumption that no trucks search for short-term parking after 16:00:00, the number of trucks entering this travel plaza suddenly decreases around this time, and most trucks at this travel plaza complete a 30-minute rest. Thus, the outflow of trucks is greater than the inflow, resulting in this drop. This sudden change might not be observed in reality in such a deterministic fashion. What is worth acknowledging again is the need for more empirical data to provide a stronger basis for assumptions.

With respect to the No-build Scenario, the model setup allows for the calculation of the daily average exceedance (%) for each travel plaza; see Table 6.2 below. The daily average exceedance is the relative amount of time in a day where the truck parking demand at a travel plaza is greater than its supply weighted by the corresponding parking demand excess. This is a combined measure of frequency and severity of the truck parking shortage for each travel plaza. It is calculated by taking the average of the positive part of the demand/legal capacity ratio minus 100%, i.e.

$$\frac{1}{n} \sum_{i=1}^n \max(\text{demand/legal capacity ratio}_i - 100\%; 0), \quad (6.1)$$

where  $n$  is the number of time intervals and  $\text{demand/legal capacity ratio}_i$  is the demand/legal capacity ratio at the interval  $i$ , which was calculated by taking the demand and dividing it by the legal capacity, with  $i = 1, \dots, n$ .  $n$  in this case is equal to 8,640. As mentioned in the previous chapter, the COM interface script stops every 10 simulation seconds to output values, and since the simulation runs for 86,400 simulation seconds (or one simulation day), there are 8,640 time intervals. The daily average exceedance is a reasonable measure of the (conditional) severity of illegal parking for this specific simulation. Note that this measure—as all further measures to follow—could be estimated in different simulations (for September 2<sup>nd</sup> or even for various days) to move from a single observation to statistically robust mean values and standard deviations or confidence intervals to assess their variability.

Table 6.2.: Daily average exceedances of travel plazas in the No-build Scenario.

Travel plaza	Daily average exceedance (%)
Angola (EB direction)	18.94
Angola (WB direction)	13.91
Chittenango	16.77
Clarence	11.22
Clifton Springs	16.46
Dewitt	11.81
Guilderland	4.22
Indian Castle	0.15
Iroquois	11.10
Junius Ponds	1.77
Malden	0.00
Modena	4.75
Mohawk	10.85
New Baltimore	14.51
Oneida	2.43
Ontario	11.40
Pattersonville	9.90
Pembroke	5.40
Plattekill	17.04
Port Byron	15.83
Ramapo	17.08
Schuyler	0.00
Scottsville	0.00
Seneca	9.86
Sloatsburg	18.03
Ulster	0.00
Warners	16.08

Referring to Table 6.2, it can be seen that the travel plazas with the greatest daily average exceedance values in descending order are Angola (EB direction), Sloatsburg, Ramapo, Plattekill, and Chittenango. These values coincide with the results from the truck parking demand model, which show that Angola (EB direction), Sloatsburg, and Plattekill experienced either extreme or high truck parking demand. Coupling the results of the truck parking demand model with the values presented in Table 6.2 provides some insight into the current situation. This narrows the focus on a select number of travel plazas for future studies that aim to investigate truck parking inadequacy on the Thruway.

These values were not calculated for the TPIMS Scenario due to the assumption that trucks do not park illegally in this scenario, or in other words, illegal parking spaces are not included. For the TPIMS Scenario, the maximum demand/legal capacity ratio is never greater than 100%, and thus, the daily average exceedance

and duration of exceedance would be 0 for all travel plazas. Therefore, the values above in Table 6.2 are presented not for the purposes of comparing the scenarios but rather for furthering understanding of the truck parking situation without a TPIMS.

To compare both scenarios, certain key parameters were calculated and are presented in Table 6.3. As already mentioned, the demand/legal capacity ratio (%) for each travel plaza was calculated by taking the demand and dividing it by the legal capacity at every point in time after 08:00:00. The maximum was then taken to arrive at the peak demand/legal capacity ratio. The duration at/above legal capacity for each travel plaza was calculated by summing every point in time where the demand was greater than or equal to the legal capacity and then multiplying this sum by the time step of 10 seconds to get the number of seconds. This value was then converted to minutes and hours. Hence, the duration at/above legal capacity is a measure of frequency, whereas the daily average exceedance above is a measure that takes into account both frequency and especially severity.

Table 6.3.: Comparison of scenarios by travel plaza.

Travel plaza	Maximum demand/legal capacity ratio (%)		Duration at/above legal capacity (minutes)		Duration at/above legal capacity (hours)	
	No-build Scenario	TPIMS Scenario	No-build Scenario	TPIMS Scenario	No-build Scenario	TPIMS Scenario
Angola (EB direction)	150	100	382	368	6.36	6.14
Angola (WB direction)	150	100	320	284	5.33	4.74
Chittenango	150	100	356	305	5.93	5.09
Clarence	150	100	244	229	4.06	3.81
Clifton Springs	152 <sup>[1]</sup>	100	333	303	5.55	5.04
Dewitt	152 <sup>[1]</sup>	100	296	279	4.93	4.66
Guilderland	150	100	182	210	3.04	3.51
Indian Castle	103	100	68	137	1.13	2.29
Iroquois	150	100	239	205	3.98	3.42
Junius Ponds	123	100	101	225	1.69	3.75
Malden	62	100	0	227	0.00	3.78
Modena	138	100	193	195	3.21	3.25
Mohawk	150	100	276	345	4.60	5.75
New Baltimore	150	100	315	290	5.26	4.83
Oneida	130	100	148	180	2.47	3.00
Ontario	150	100	275	296	4.58	4.93
Pattersonville	150	100	219	202	3.65	3.36
Pembroke	150	100	187	169	3.11	2.82
Plattekill	150	100	362	340	6.03	5.67
Port Byron	150	100	328	252	5.46	4.21
Ramapo	150	100	349	334	5.81	5.56
Schuyler	80	100	0	167	0.00	2.78
Scottsville	35	100	0	38	0.00	0.64
Seneca	150	100	225	215	3.75	3.58
Sloatsburg	150	100	375	382	6.26	6.36
Ulster	95	100	0	163	0.00	2.71
Warners	151 <sup>[1]</sup>	100	350	325	5.84	5.42

<sup>[1]</sup> This value is above 150% due to rounding.

Plotting the duration at/above legal capacity of the TPIMS Scenario against that of the No-build Scenario facilitates comparison; see Figure 6.6.

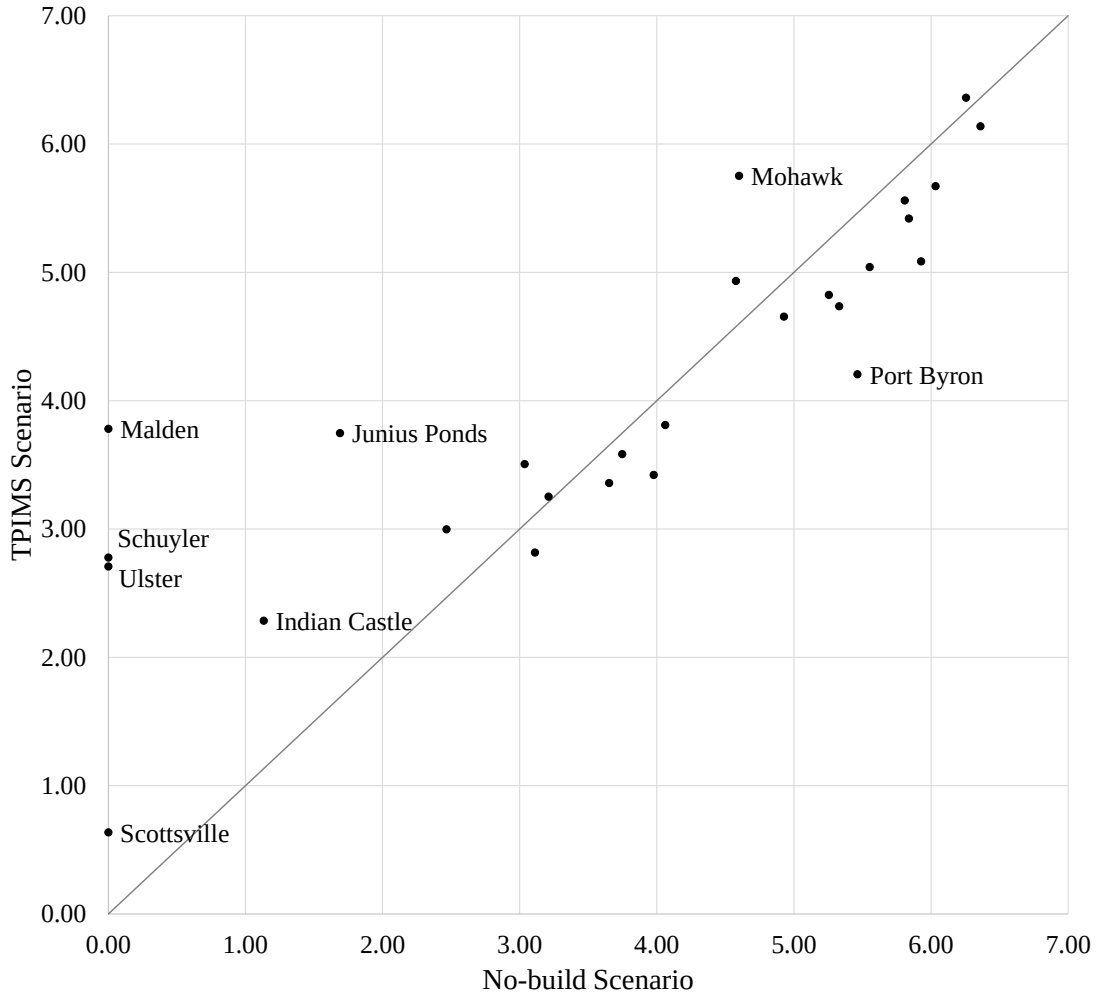


Figure 6.6.: Comparison of duration at/above legal capacity between the No-Build Scenario and the TPIMS Scenario. The x- and y-axis are in units of hours. Outliers are labeled with travel plaza names.

In this figure, outliers are labeled with travel plaza names. The angle bisector, i.e.  $y = x$ , is plotted. Travel plazas falling on this line represent those with the same duration at/above legal capacity for both scenarios. Pointing out a few of the outliers, almost all fall above this line, indicating an increase in the duration at/above legal capacity with the implementation of a TPIMS. However, Port Byron falls below the line, which has a duration at/above legal capacity of 4.21 hours in the TPIMS Scenario compared to 5.46 hours in the No-build Scenario. Considering all travel plazas, most fall near the angle bisector, meaning that most do not experience a considerable change in duration at/above legal capacity with the implementation of a TPIMS.



Referring to the No-build Scenario, the previous table shows that almost all travel plazas reach a maximum demand/legal capacity ratio of 150%, and four stay below 100%. In a case study, this would have to be validated with empirical observations to see whether this very high demand can be observed. It could be that the model with its assumptions is rather conservative here; however, the day with the highest traffic volume was used, so these results are justifiable. Regarding the duration at/above legal capacity, several travel plazas are full for several hours and, hence, potentially all night. This indicates a severe and systematic lack of parking supply, which is in line with the Jason's Law Truck Parking Survey results listed in Chapter 2.

Concerning the TPIMS Scenario, all travel plazas reach a maximum demand/legal capacity ratio of 100%, including the ones that were below 100% in the No-build Scenario. In comparison to the No-build Scenario, 15 travel plazas have a smaller duration at/above legal capacity.

In order to compare the two scenarios, HOS violations were calculated. Figure 6.7 below shows the number of HOS exceedances by scenario, i.e. the number of trucks that drove above the allocated driving time before parking. The numbers reported for vehicle type 210 represent trucks that drove more than 8 hours before parking, whereas the numbers for vehicle type 220 represent trucks that exceeded the 11-hour driving limit.

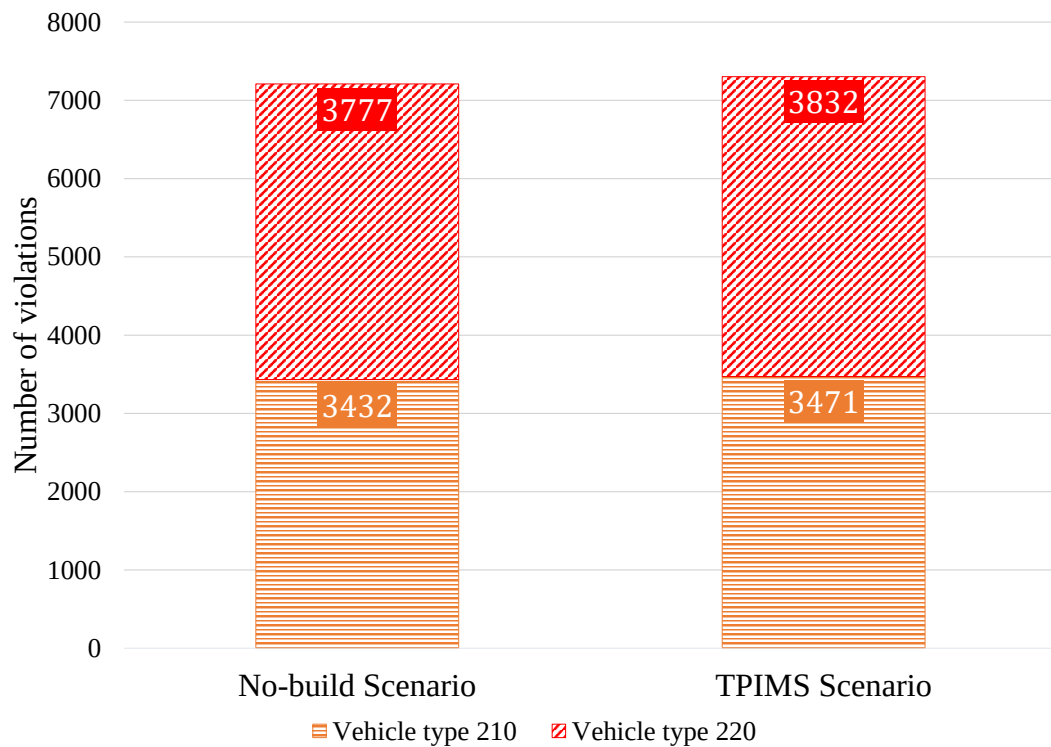
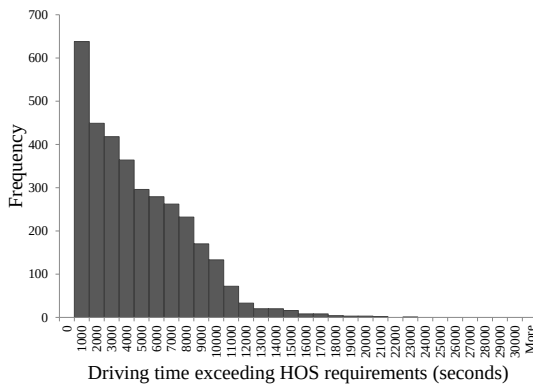


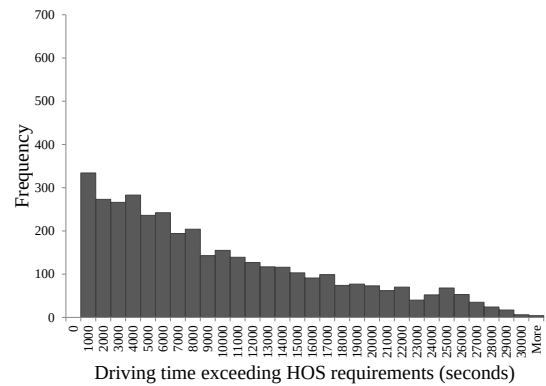
Figure 6.7.: Number of HOS exceedances by scenario.

Referring to the figure above and specifically looking at vehicle type 210, there was only a slight increase in the number of HOS exceedances for the TPIMS Scenario. The same applies for vehicle type 220.

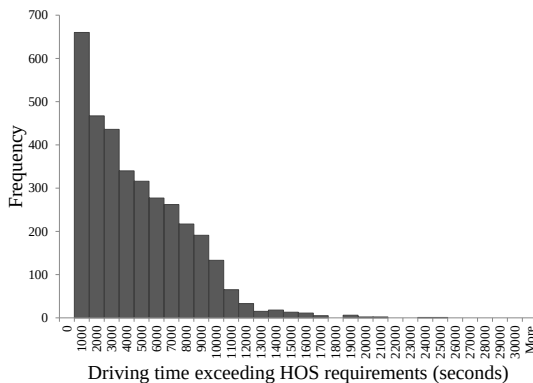
Comparing just the number of exceedances does not provide substantial insight into the HOS violations in both scenarios. It is important to look at the *severity* of HOS exceedances. *Severity* is defined by the author as the extent a truck operator drives beyond HOS regulations. Figure 6.8 below plots four histograms, each showing the frequency and severity of HOS exceedances by scenario and vehicle type.



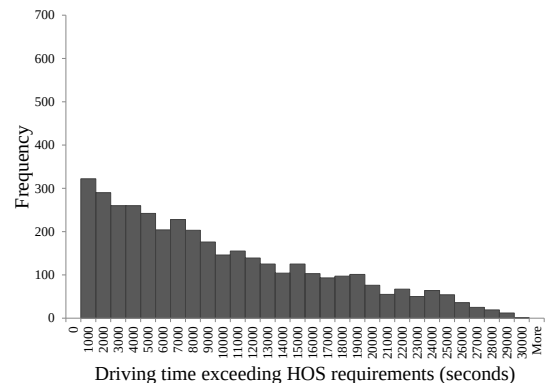
(a) No-build Scenario: Vehicle type 210.



(b) No-build Scenario: Vehicle type 220.



(c) TPIMS Scenario: Vehicle type 210.



(d) TPIMS Scenario: Vehicle type 220.

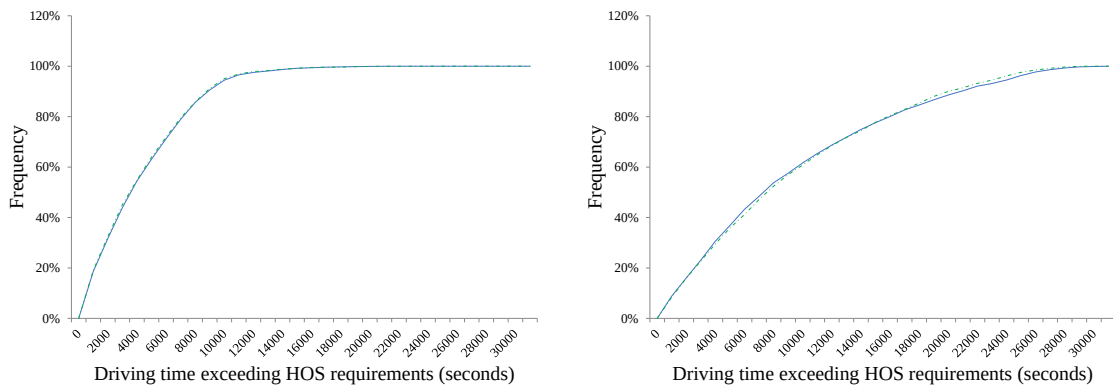
Figure 6.8.: Frequency of severity of HOS exceedances by scenario and vehicle type.

This figure illustrates that there are only minor differences between the scenarios with respect to the severity of HOS exceedances. Based on the model setups of the No-build Scenario and TPIMS Scenario, one could argue that these similar findings make sense. To remind the reader, in the No-build Scenario in Vissim, when a truck searching for short or long-term parking reaches a dynamic vehicle routing decision upstream of a travel plaza, it is redirected towards the travel plaza even if there is no available parking. The truck then waits until an available parking space becomes available, during which their driving time is still

accruing. Thus, a truck in this situation could violate HOS regulations just waiting for parking to become available. In the TPIMS Scenario, on the other hand, when a truck searching for parking reaches a dynamic vehicle routing decision upstream of a travel plaza that is full, it is redirected towards the next downstream travel plaza. While driving to the next travel plaza, the driving time of the truck also accrues, which could cause the truck to violate HOS regulations en route to the next travel plaza. This argument is also supported by the fact that there is a high probability mass at parking exceedance of even 1–3 hours, indicating that in both scenarios trucks are waiting for a long time to be able to park (No-build Scenario) or drive a long-time passing several travel plazas that are all full (TPIMS Scenario).

Based on the four histograms above and specifically looking at the first few bins, a large number of trucks violate HOS regulations by 2000 seconds (or approximately 30 minutes). This means that a large number of trucks find parking within the 30 minutes past the violation thresholds (8 hours for trucks searching for short-term parking and 11 hours for trucks searching for long-term parking). This indicates that the assumed time of 30 minutes given to trucks to find parking might not be large enough.

Both scenarios can be compared with cumulative frequency diagrams; see Figure 6.9.



(a) Vehicle type 210.

(b) Vehicle type 220.

Figure 6.9.: Cumulative frequency of severity of HOS exceedances of both scenarios by vehicle type. The solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Based on this figure, one could reasonably conclude that there is not a substantial difference between the two scenarios with respect to the severity of HOS exceedances.

Summarizing this section on the TPIMS modeling task, a comparison of the two scenarios, the No-Build Scenario and the TPIMS Scenario, was done. It was found that certain travel plazas have an increase in the number of trucks parked at the facility due to the implementation of a TPIMS, whereas others have a decrease. The same applies for the duration at/above legal capacity. This indicates that the TPIMS is distributing parking demand along the NYS Thruway. Regarding the number of HOS violations and the severity of them, results show no substantial difference between the two scenarios. As emphasized, further empirical studies are necessary to draw conclusions.

## 7. Conclusions and Recommendations

This chapter concludes this thesis with first a summary of contributions, which explains the added value of this research and provides an overview of how the objectives were addressed. Second, the chapter contains a section dedicated to the assumptions and limitations of this work. Ending this chapter is a section on future work, which might address some of the aforementioned limitations.

### 7.1. Summary of contributions

The first research question of this thesis framed the truck parking demand modeling task, which included two objectives. The first objective was to investigate previous studies in order to find methodologies for truck parking demand modeling in traffic flow simulation software. This is addressed in the literature review of this work, Chapter 3; however, the outcome of the literature review is that previous work on this specific subject is lacking. The second objective was to recommend a methodology for employing Vissim to model truck parking demand, which is described in detail in Chapter 5. It was found that it is possible to perform truck parking demand analysis in Vissim. To the best knowledge of the author, this is the first work that provides a framework for employing this microscopic traffic simulation software for such an analysis.

The second research question framed the TPIMS modeling task, which included two additional objectives. The first objective was to model the NYS Thruway and selected travel plazas in Vissim, as explained in Chapter 5 of the current work. The second objective was to conduct a scenario analysis where the No-build Scenario and the existing the TPIMS Scenario were modeled and evaluated. The results of this analysis are presented and discussed in Chapter 6. Generally, it was possible to evaluate a TPIMS using Vissim, but some limitations with the software and the lack of available data required a set of assumptions. These assumptions could potentially be addressed in future work; however, with the focus being on demonstrating the applicability of Vissim on modeling a TPIMS, addressing all assumptions was outside the scope of this thesis. Recommended future work is described below in Section 7.3.

## **7.2. Assumptions and limitations**

As elaborated in Chapter 5, the truck parking demand model and both models associated with the TPIMS modeling task were founded on a set of assumptions. The lack of empirical data, e.g. data on the driving history of trucks before they enter the Thruway, results in model limitations. The key assumptions and limitations of this work are itemized below.

- Neither the truck parking demand model nor both models associated with the TPIMS modeling task were calibrated or validated. The validity of the results could not be determined.
- Only NYS Thruway travel plazas were considered viable parking options in the models. Private parking facilities, which are located outside of the Thruway system, were not taken into account despite their close proximity to the highway.
- The models do not contain any vehicles, either driving or already parked, at the start of a simulation. As a consequence, time is required until the simulation reaches a realistic steady state, which is referred to as the burn-in period. This results in the focus to be limited to the time period from after 08:00:00 to 23:59:50.
- Trucks were assumed to follow the same HOS schedule. Short-term and long-term parking were assumed to be 30 minutes and 10 hours, respectively. Desired speed distributions were assumed. Trucks were no longer changed to vehicle type 210 if they enter the network after 16:00.
- The departure time of a vehicle was calculated by taking its interval beginning time, converting it into seconds, and adding a random value between 0 and 3,600 seconds, assuming a uniform distribution of entry times over the full hour.
- Due to the lack of data and the effort needed to get the pre-network driving time of every truck, the pre-network driving times were calculated based on an assumed function of their start times.
- All travel plazas were assigned a set number of legal truck parking spaces as well as an assumed number of illegal truck parking spaces.
- The behavior of truck drivers in the No-build Scenario and in the TPIMS Scenario were assumed, i.e. truck operators wait for parking to become available in the No-build Scenario and do not park illegally in the TPIMS Scenario.

- The results of the current work were based on output from a single simulation run per model. This means that for the truck parking demand model, for instance, the results are based on only one observation of the random variables incorporated in Vissim and the COM interface script.

As already mentioned in Section 5.2.4, the purpose of this thesis is neither to provide highly accurate estimates of truck parking demand nor to conduct an overly thorough scenario analysis of a TPIMS on the NYS Thruway, but rather is meant to demonstrate the general methodology of how Vissim may be used to perform such an in-depth study. All reported numbers in this thesis should be approached with caution, and focus should be placed on the time period of 8:00:00 to 23:59:50. With the assumptions described in Chapter 5, approximating potentially realistic behavior was an aim of this work. Indeed, this thesis demonstrated that Vissim is generally applicable to achieve realistic modeling results. However, case studies require more case-specific empirical input or even surveys and expert assessments for a well-suited model calibration and validation.

### **7.3. Recommended future work**

In light of the assumptions and limitations discussed above, a non-exhaustive list of recommendations for future work to build upon and improve the current study is provided below.

- Both the truck parking demand model and both models associated with the TPIMS modeling task should be calibrated and validated using empirical observation, such as through surveying the truck parking demand over time at each travel plaza.
- As previously mentioned, the assumed equation that calculates the pre-network driving time of each truck either should be calibrated or more information should be gathered to more accurately model the pre-network driving time. Expert judgment could provide insight into the pre-network driving time distributions at given entrance points. These distributions could be estimated based on knowledge of surrounding infrastructure, interchanges, industry, etc. Information gathering could be facilitated by an online survey platform. Another method could involve observing the real parking situation at a travel plaza and directly surveying truck drivers to ascertain pre-network driving time distributions for individual entrance points.
- A multi-day analysis would provide more insight into the true behavior of truck parking demand. This would incorporate carryover, which would result in more appropriate parking demand graphs over full days. The other HOS rules listed in Chapter 2—e.g. the 60-hour on-duty limit, the 70-hour on-duty limit, and the 34-hour restart—could be modeled in a multi-day simulation. In addition, weekday/weekend effects could be analyzed.

- To address the limitation that the results were based on output from single simulation runs, repeated simulations of the same day should be completed to get different observations of the random variables incorporated in Vissim and the COM interface script. Furthermore, running multiple simulations for different days (with different trip chain files) would yield more sophisticated statistical estimates of the results including measures of confidence. Thus, by utilizing Monte Carlo analysis techniques and more advanced statistical methods, future work could carry this out.

The assumptions and limitations listed above point to the aforementioned statement that the results herein are only exemplary since the focus was on demonstrating the applicability of Vissim of modeling a TPIMS on the NYS Thruway. Collecting necessary empirical data and calibrating the model assumptions were outside the scope of this thesis work. Nevertheless, as emphasized by the extent of potential future research topics, the methodology elaborated in this thesis serves as a fruitful starting point for future work.



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# APPENDICES

## **A. Supplemental Information from Jason's Law Truck Parking Survey**

Based solely on FHWA (2015), Appendix A summarizes findings from the Jason's Law Truck Parking Survey that are supplemental to the current work.

### **A.1. Approaches to measuring truck parking adequacy**

As required by Jason's Law, FHWA developed a set of metrics to measure the adequacy of truck parking. To carry out this work, FHWA held a workshop to get input from key industry groups and public agency representatives as well as performed a desk scan, through which previous studies by public agencies and stakeholders were reviewed. The desk scan revealed that adequacy was most commonly addressed "in terms of truck parking demand and available parking spaces at geographic scales that ranged from highway corridors to a national level" (FHWA, 2015, p. 82).

FHWA found that the adequacy of truck parking is complex to measure at any level of geography since parking demand and parking supply are dynamic. Long-term parking demand is based on both the HOS regulations a driver must obey in addition to logistical patterns that are influenced by market forces. Generally, the following aspects impact truck parking demand: origin and destination; length and route of trip; delivery schedules for shippers, receivers, and terminals; unforeseen congestion and related delay; and HOS regulations.

In evaluating truck parking demand, understanding the amount of origin and destination freight traffic is essential because this helps to identify areas with high truck traffic, which tend to have a high level of competition for long-term parking. The lengths and routes of freight trips are also important to consider. Taking into account HOS requirements and knowing preferred routes, they—along with delivery schedules—provide insight into which truck parking locations are preferred. Congestion introduces uncertainty in the evaluation and causes delays, forcing truck drivers to reroute and identify other parking options.

Whenever there is a need for long-term parking, a truck driver should ideally have access to a parking space. However, when demand exceeds supply, a parking shortage occurs, which is caused by a discrepancy between demand for park-

ing at a location and point in time and the availability of adequate parking space at that location and point in time. Parking shortages force truck drivers into a situation where they must choose the lesser of two evils: either continue driving to find parking elsewhere and face the risk of violating HOS regulations or park illegally at unofficial locations, such as on shoulders, ramps, or local streets.

Through the aforementioned desk scan, FHWA found that parking adequacy has been measured using six approaches, which are enumerated below.

1. **Facility-based approach:** This approach is used to model truck parking activity at a facility. A probability function that relates truck volume on the highway, the distance to nearest facilities, and the amenities at the facility represents parking demand. The American Association of State Highway and Transportation Officials (AASHTO) applies this approach for measuring and predicting parking at rest areas; see the American Association of State Highway and Transportation Officials (AASHTO, 2001).
2. **Basic corridor-based approach:** Similar to the facility-based approach, a basic corridor-based approach groups facilities along highway corridors so that multiple facilities can be analyzed. Using this method in conjunction with travel time data allows for the impacts of congestion on truck parking demand to be measured.
3. **Corridor-based approach with trip end considerations:** An extension of the basic corridor-based approach, this approach is suited for large geographic regions. Using national data, e.g. from FHWA's Freight Analysis Framework (FAF), this method identifies truck trip origins and destinations and links "those trip ends to parking demand along corridors based on service windows and driver rest periods for trucks traveling between these origin and destination points" (FHWA, 2015, p. 85).
4. **Enhanced corridor-based approach:** Using a combination of the three previously described approaches, this method additionally considers parking characteristics at trip ends that are related to truck staging, load scheduling, and terminal operations. In comparison with the previous three methods, this approach is advantageous since it can measure latent parking demand without considering parking capacity constraints at facilities.
5. **Real-time parking data collection:** Video cameras, loop detectors, and a combination of technologies have been used in several studies to monitor truck parking activity. Data collection is generally intended to deliver real-time parking information to truck drivers; however, this technology enables massive amounts of data to be collected by time of day, season, and any other time frame.

6. **Anecdotal information:** A valuable resource for measuring adequacy of truck parking facilities is often anecdotal information, which can be collected through surveys. Although this approach provides valuable insight, a downside is that the information gathered may not easily translate to metrics or direct measurements of performance.

Previous studies that investigated truck parking applied one or a combination of the six methods, generally approaching the issue from one of two perspectives: a “facility-based” approach or a “travel-based” approach. The former, which is typically used by State DOTs, estimates parking demand for rest areas on the NHS based on traffic volumes by vehicle class. The latter measures parking demand based on the origins and destinations of CMVs, time of day, HOS restrictions, and other factors.

## A.2. Truck parking metrics

As parking supply and demand are highly complex, not only a single metric, but a set of metrics is needed to measure the adequacy of truck parking. The following lists the recommended metrics, which are divided into tiers. Tier I is the foundation from which Tiers II and III build upon. All of these metrics can be applied at various geographic levels to evaluate truck parking. Some metrics are more appropriate when conducting a corridor-based approach, whereas others lend themselves to a facility-based approach. Providing a complete description of these metrics is outside the scope of this thesis. Therefore, the interested reader is directed towards FHWA (2015) for a more in-depth discussion of these metrics.

### A.2.1. Tier I metrics

Tier I metrics are the most readily available metrics that can provide valuable insight into truck parking supply and demand. These metrics are currently used at the national level as well as at a state and regional level when truck parking needs are considered. Much of the data is publicly available; however, some of the data comes from private sources. Moreover, some of these metrics are obtained through surveys by states. The recommended Tier I metrics are *truck travel on the NHS*, *number of spaces (public and private)*, *number of spaces in relation to NHS mileage*, *number of spaces in relation to VMT*, and *number of spaces in relation to GDP by state*.

### A.2.2. Tier II metrics

Unlike Tier I metrics, Tier II metrics, which are also used to illustrate truck parking needs, are cost- and data-intensive because data must be purchased and/or routine surveys must be done to collect information. The recommended Tier II



metrics are utilization for public and private facilities (hourly, weekly, and monthly), parking needs by driver type, parking needs by industry represented, OD information, inventory of problem locations, proximity to industry and highway facilities, HOS violations, fatigue-related crashes, amenities at parking facilities, and inventory of driver perceived shortages and parking challenges.

Time-of-day utilization provides an indication of how truck parking activity fluctuates at a facility with the time of day. “[T]he temporal distribution of truck parking at these facilities over a day or week is considered to be indicative of parking needs associated with latent parking demand measured using other resources” (FHWA, 2015, p. 96). Figure A.1 below exemplifies a 24-hour parking accumulation profile at six sampling locations in the North Jersey Transportation Planning Authority (NJTPA) region.




Figure removed due to possible copyright infringements.

Figure A.1.: Twenty-four hour parking accumulation profile (FHWA, 2015).

### A.2.3. Tier III metrics

Tier III metrics are not widely used due to limited data availability but could deepen the understanding of truck parking needs. The recommended Tier III metrics are *impact of congestion on travel time and resulting driving distance and need for parking, average haul length, use of technology to determine parking availability, return on investment for parking development, optimization of return on investment, business locations and industrial land uses, employment by industry for truck facilities, diesel fuel sales, parcel size and zoning, environmental impact metrics, crime reports by location, reported parking violations on NHS, and fixed-object crashes with trucks on highway shoulders.*

## B. Further Data Analysis

Appendix B presents two supplemental figures that visualize the NYS Thruway OD data.

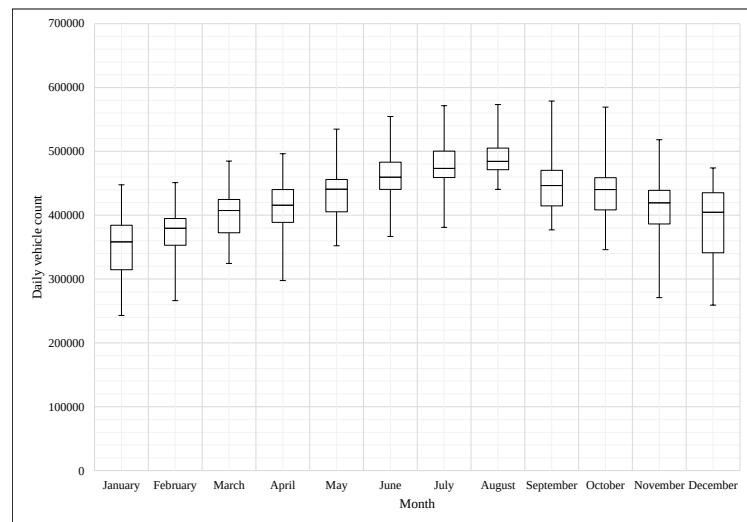


Figure B.1.: Box plots of NYS Thruway daily vehicle count by month.

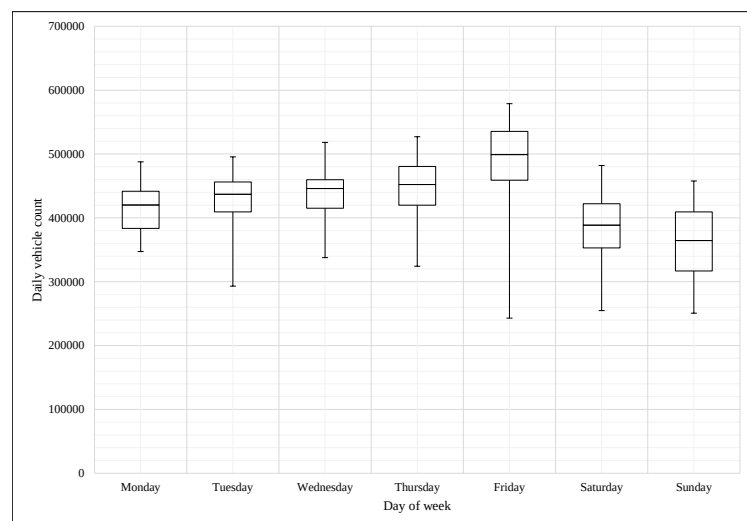


Figure B.2.: Box plots of NYS Thruway daily vehicle count by day of week.

## C. Vissim Model Development

Appendix C provides screenshots showing how Vissim was configured. All figures in this appendix show settings applied to both the truck parking demand modeling task and the TPIMS modeling task unless otherwise specified.

### C.1. Initial setup

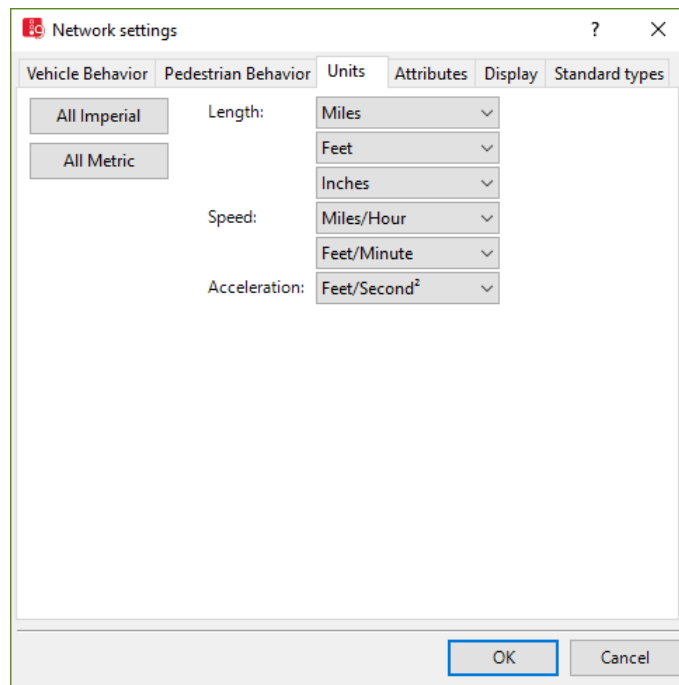


Figure C.1.: *Network Settings* window, *Units* tab.

## C.2. Road network modeling

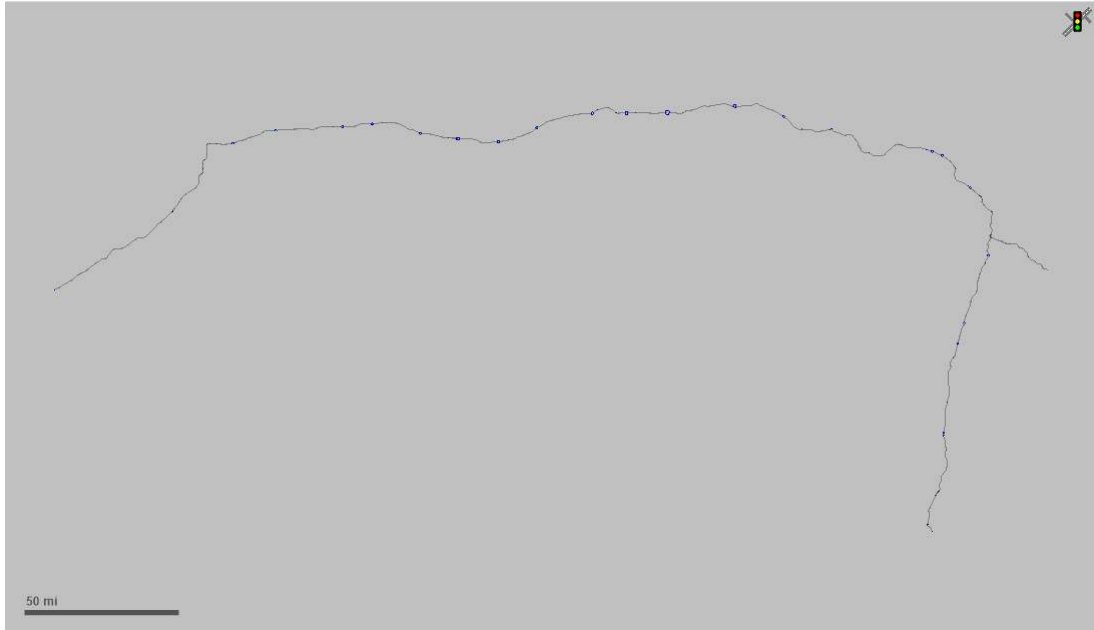


Figure C.2.: Full Vissim network.

## C.3. Entrance/exit point modeling

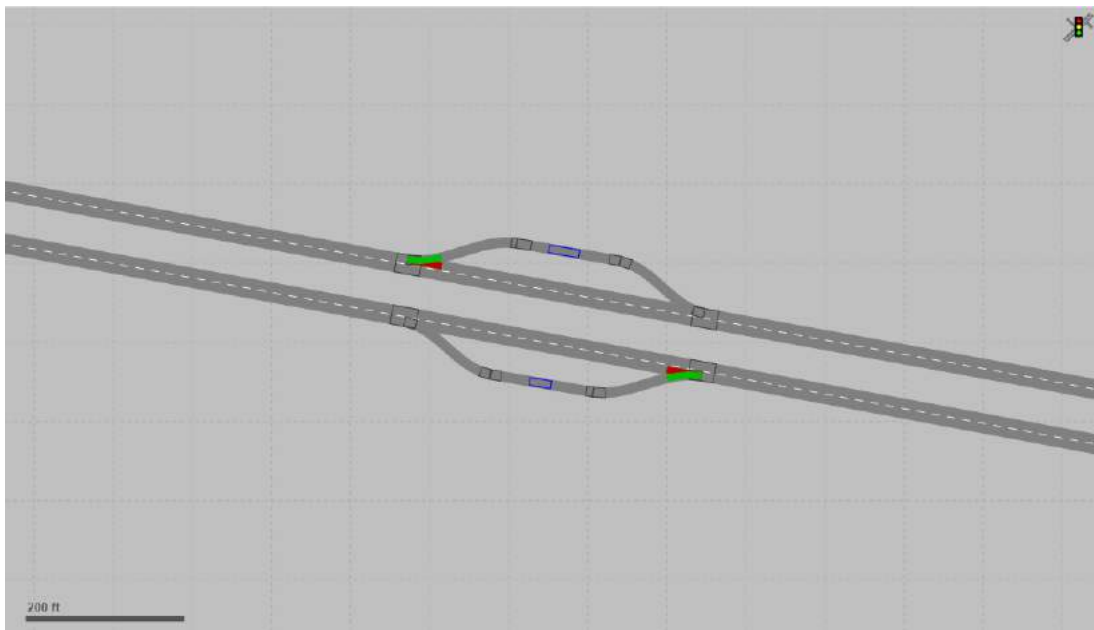


Figure C.3.: Example entrance/exit point.

## C.4. Travel plaza modeling



Figure C.4.: Example travel plaza.

## C.5. Vehicle types/vehicle classes

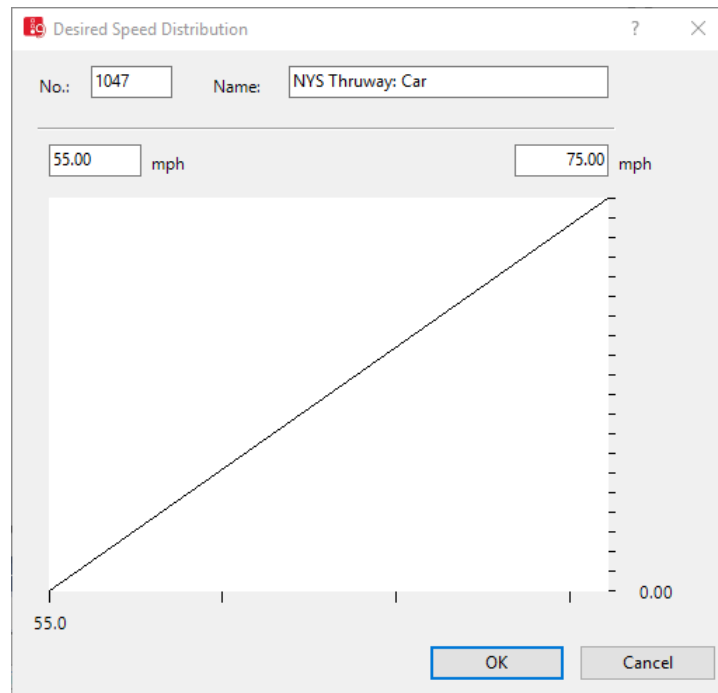
Vehicle Types							
Select layout...							
Coun	No	Name	Category	Model2D3DDistr	ColorDistr1	OccupDistr	Capacity
1	100	Car	Car	10: Car	1: Default	1: Single Occupancy	0
2	200	Truck	HGV	20: HGV	1: Default		0
3	210	Truck searching for short-term parking	HGV	20: HGV	1: Default		0
4	211	Truck parked short term	HGV	20: HGV	1: Default		0
5	220	Truck searching for long-term parking	HGV	20: HGV	1: Default		0
6	221	Truck parked long term	HGV	20: HGV	1: Default		0
7	300	Bus	Bus	30: Bus	1: Default	1: Single Occupancy	110
8	400	Tram	Tram	40: Tram	1: Default	1: Single Occupancy	215
9	510	Man	Pedestrian	100: Man	101: Shirt Man		0
10	520	Woman	Pedestrian	200: Woman	201: Shirt Woman		0
11	610	Bike Man	Bike	61: Bike Man	101: Shirt Man		0
12	620	Bike Woman	Bike	62: Bike Woman	201: Shirt Woman		0

Figure C.5.: *Vehicle Types* list.

Vehicle Classes / Vehicle Types					
Select layout...  Vehicle types					
Count: 1	No	Name	VehTypes	UseVehTypeColor	Color
1	10	Car	100	<input type="checkbox"/>	(255, 64, 64, 64)
2	20	Truck	200	<input type="checkbox"/>	(255, 38, 127, 0)
3	30	Bus	300	<input checked="" type="checkbox"/>	(255, 0, 0, 0)
4	40	Tram	400	<input checked="" type="checkbox"/>	(255, 0, 0, 0)
5	50	Pedestrian	510,520	<input checked="" type="checkbox"/>	(255, 0, 0, 0)
6	60	Bike	610,620	<input checked="" type="checkbox"/>	(255, 0, 0, 0)
7	70	Truck searching for short-term parking	210	<input type="checkbox"/>	(255, 255, 106, 0)
8	80	Truck parked short term	211	<input type="checkbox"/>	(255, 255, 106, 0)
9	90	Truck searching for long-term parking	220	<input type="checkbox"/>	(255, 255, 0, 0)
10	100	Truck parked long term	221	<input type="checkbox"/>	(255, 255, 0, 0)

Figure C.6.: Vehicle Classes/Vehicle Types list.

## C.6. Desired speed distributions/vehicle compositions

Figure C.7.: Desired speed distribution of *NYS Thruway: Car*.

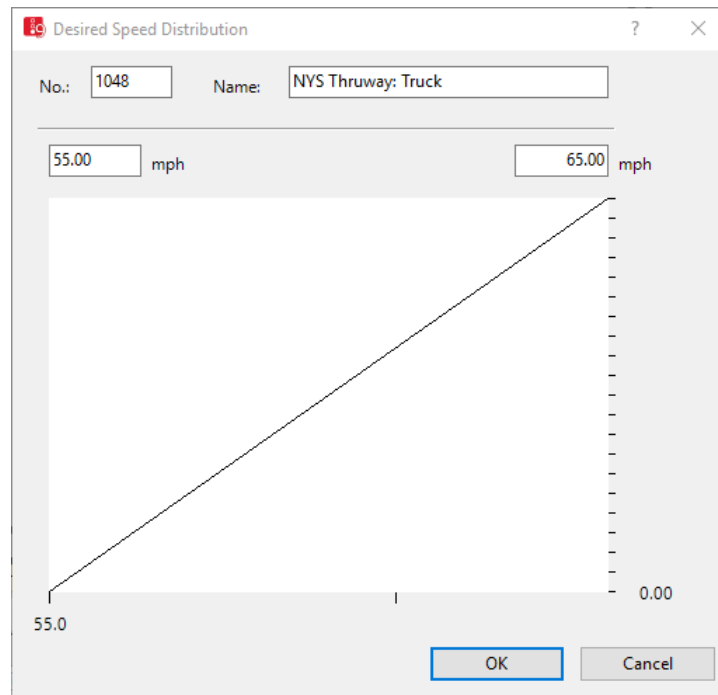


Figure C.8.: Desired speed distribution of *NYS Thruway: Truck*.

Vehicle Compositions / Relative Flows			
Select layout...			
Coun	No	Name	
1	1	NYS Thruway	
Count	VehType	DesSpeedDistr	RelFlow
1	100: Car	1047: NYS Thruway: Car	0.600
2	200: Truck	1048: NYS Thruway: Truck	0.080
3	210: Truck searching for short-term parkin	1048: NYS Thruway: Truck	0.080
4	211: Truck parked short term	1048: NYS Thruway: Truck	0.080
5	220: Truck searching for long-term parking	1048: NYS Thruway: Truck	0.080
6	221: Truck parked long term	1048: NYS Thruway: Truck	0.080

Figure C.9.: *Vehicle Compositions/Relative Flows* list.

## C.7. Dynamic assignment parameters

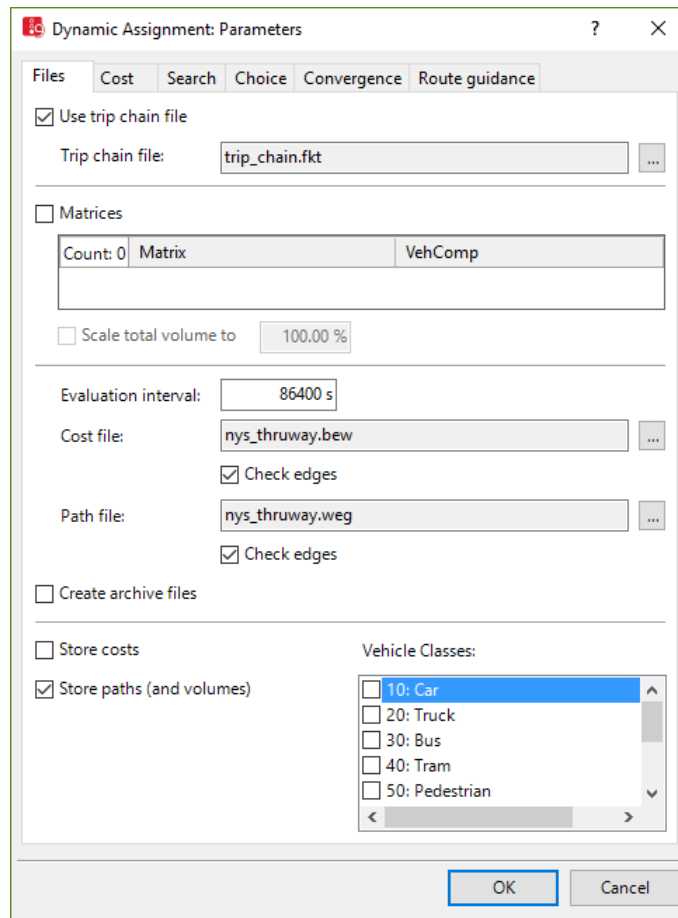


Figure C.10.: *Dynamic Assignment: Parameters* window, *Files* tab.



## C.8. Dynamic vehicle routing

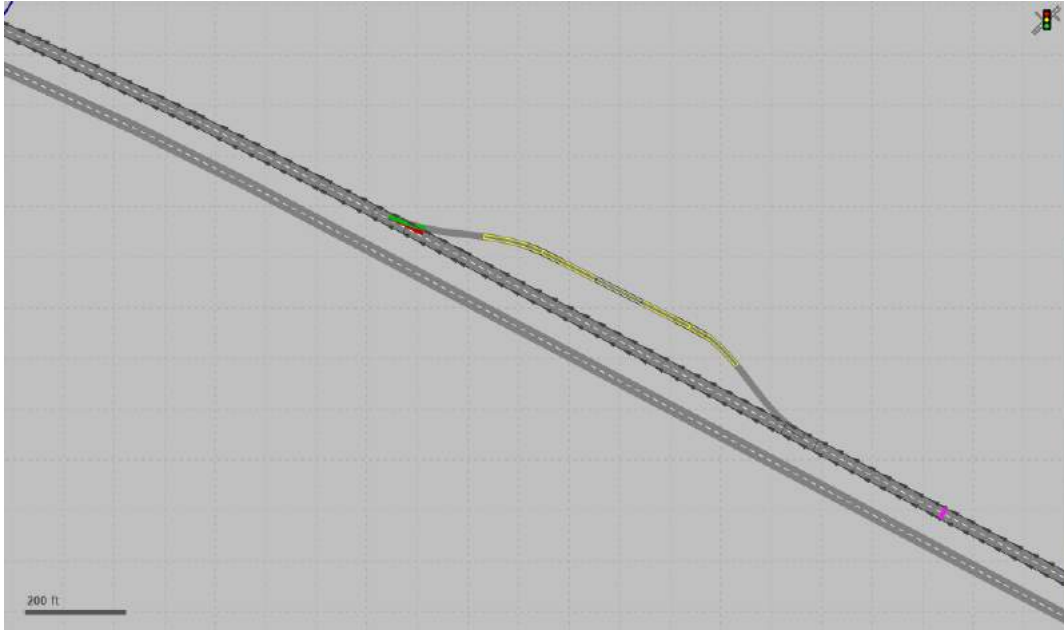


Figure C.11.: Dynamic vehicle routing decision upstream from travel plaza.

Count	No	Name	Link	Pos	AllVehTypes	VehClasses	Condition	CondParkLot	AvailSpaces	Strategy	StratParkLot	Exc/FullParkLots
1	1	1	249454.418		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	117: angola (i-90_eb)	<input checked="" type="checkbox"/>
2	2	26	85101.381		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	116: angola (i-90_wb)	<input checked="" type="checkbox"/>
3	3	274	234.094		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	115: clarence	<input checked="" type="checkbox"/>
4	4	169	104167.722		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	118: pembroke	<input checked="" type="checkbox"/>
5	5	7	129589.296		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	119: ontario	<input checked="" type="checkbox"/>
6	6	167	128311.574		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	120: scottsville	<input checked="" type="checkbox"/>
7	7	27	10051.955		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	121: seneca	<input checked="" type="checkbox"/>
8	8	164	50954.160		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	122: clifton_springs	<input checked="" type="checkbox"/>
9	9	163	16887.848		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	123: junius_ponds	<input checked="" type="checkbox"/>
10	10	162	52332.715		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	124: port_byron	<input checked="" type="checkbox"/>
11	11	161	9446.931		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	125: warrens	<input checked="" type="checkbox"/>
12	12	159	32404.646		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	126: dewitt	<input checked="" type="checkbox"/>
13	13	154	23910.782		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	127: chittenango	<input checked="" type="checkbox"/>
14	14	155	90634.996		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	128: oneida	<input checked="" type="checkbox"/>
15	15	151	38264.112		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	129: schuyler	<input checked="" type="checkbox"/>
16	16	148	2277.761		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	131: indian_castle	<input checked="" type="checkbox"/>
17	17	147	83410.418		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	130: roquois	<input checked="" type="checkbox"/>
18	18	142	7808.256		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	132: mohawk	<input checked="" type="checkbox"/>
19	19	71	45280.270		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	133: pattersonville	<input checked="" type="checkbox"/>
20	20	126	2573.599		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	134: guilderland	<input checked="" type="checkbox"/>
21	21	135	32089.115		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	135: new_baltimore	<input checked="" type="checkbox"/>
22	23	73	299836.445		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	137: malden	<input checked="" type="checkbox"/>
23	24	135	196144.615		<input type="checkbox"/>	70 90	Always		0	Specified parking lot	138: ulster	<input checked="" type="checkbox"/>

Figure C.12.: Dynamic Vehicle Routing Decisions list.

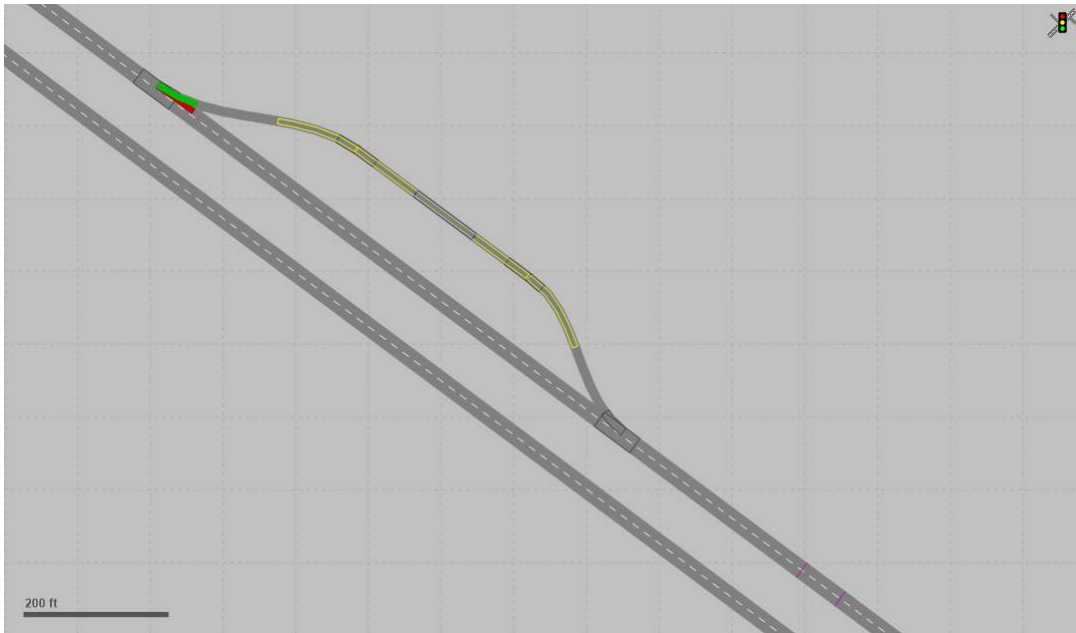


Figure C.13.: Dynamic vehicle routing decisions upstream from travel plaza in TPIMS Scenario.

## C.9. Simulation parameters

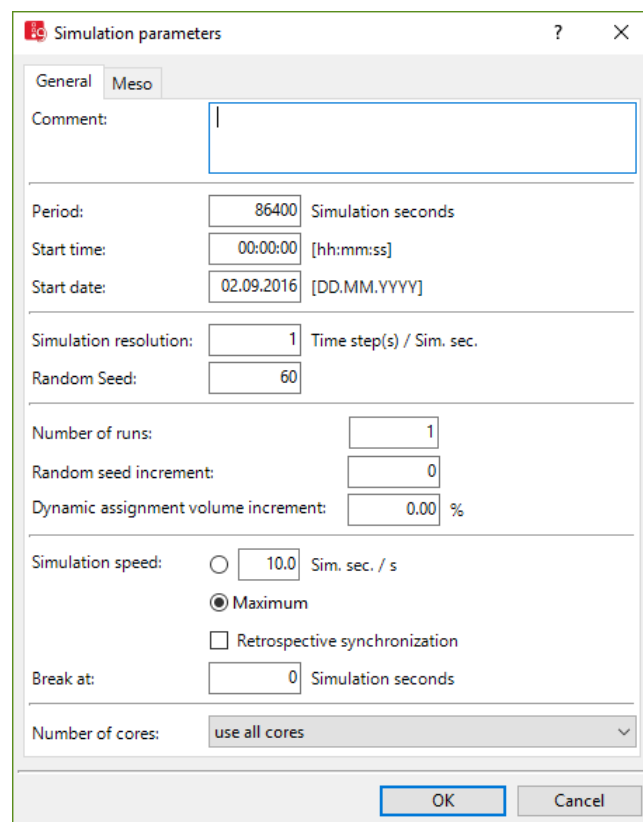
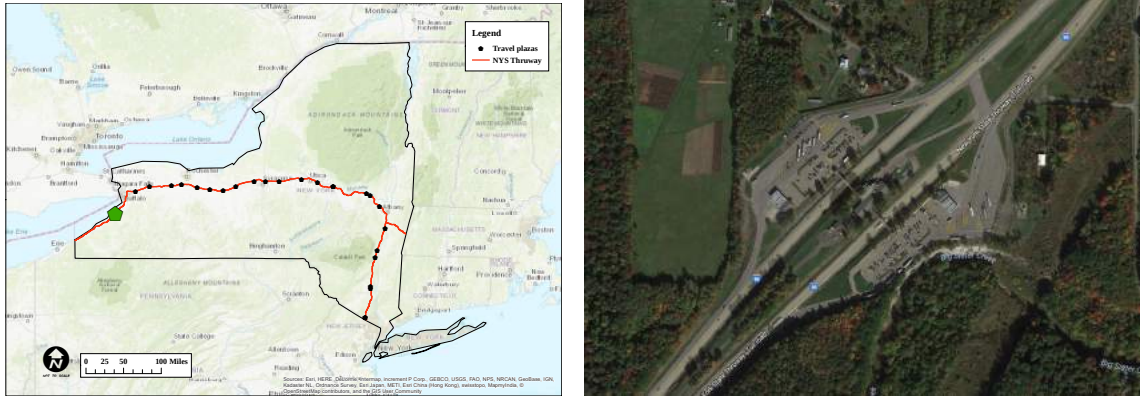


Figure C.14.: Simulation Parameters window, General tab.

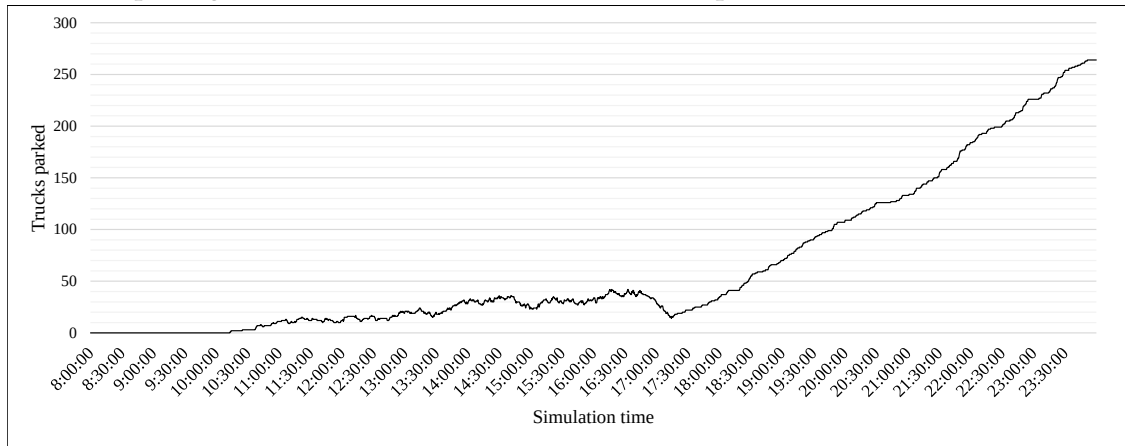
## D. Further Results

Appendix D provides supplemental figures that report the results of both the truck parking demand modeling task and the TPIMS modeling task.

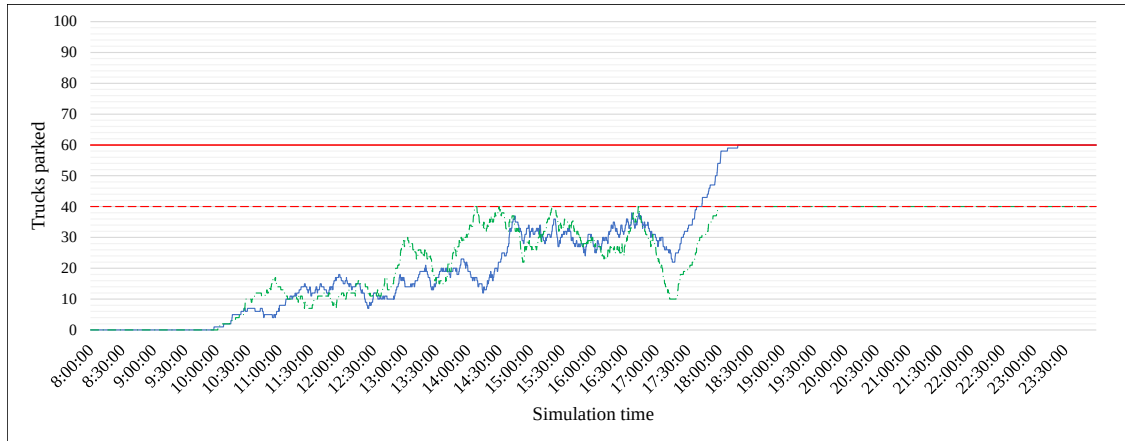


(a) Green pentagon indicates location.

(b) Aerial photo.

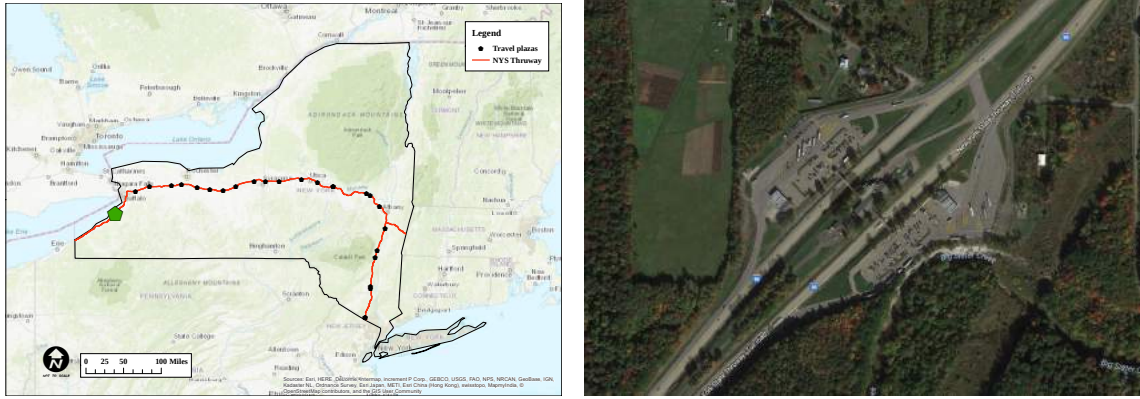


(c) Truck parking demand over day.



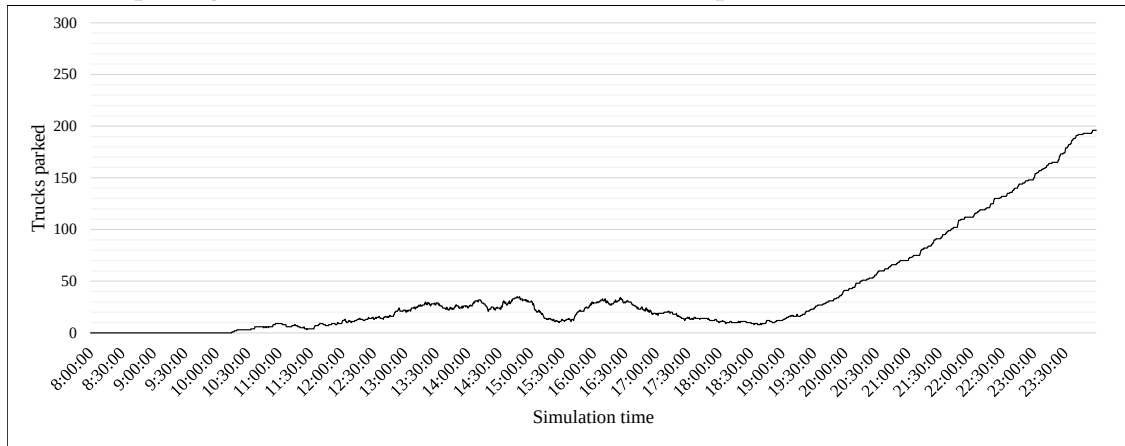
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.1.: Angola travel plaza (EB direction).

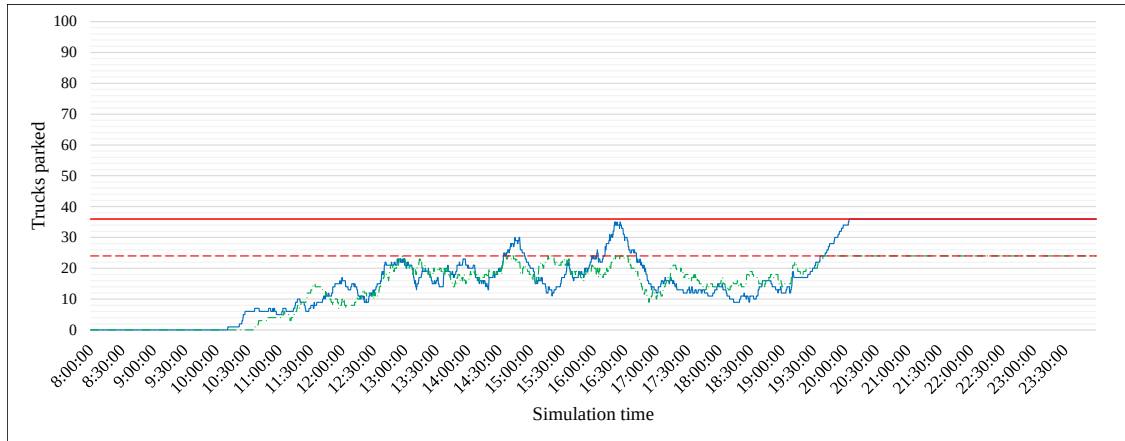


(a) Green pentagon indicates location.

(b) Aerial photo.

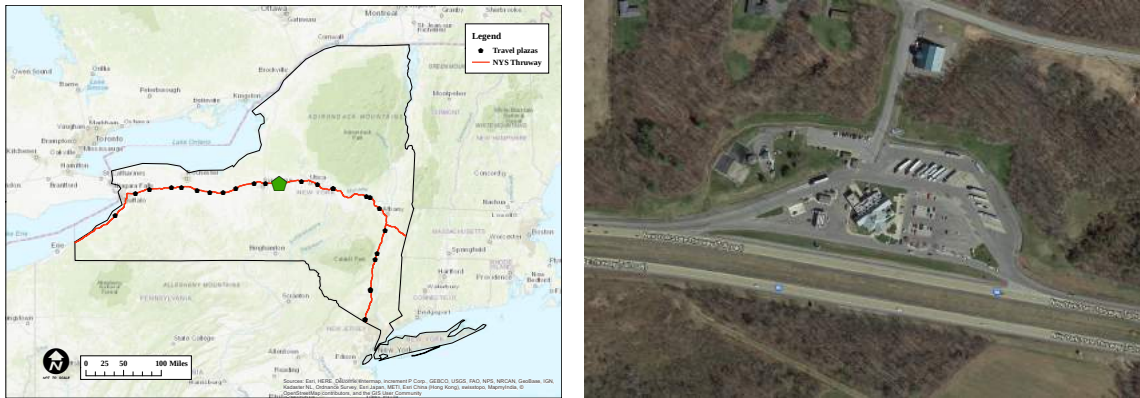


(c) Truck parking demand over day.



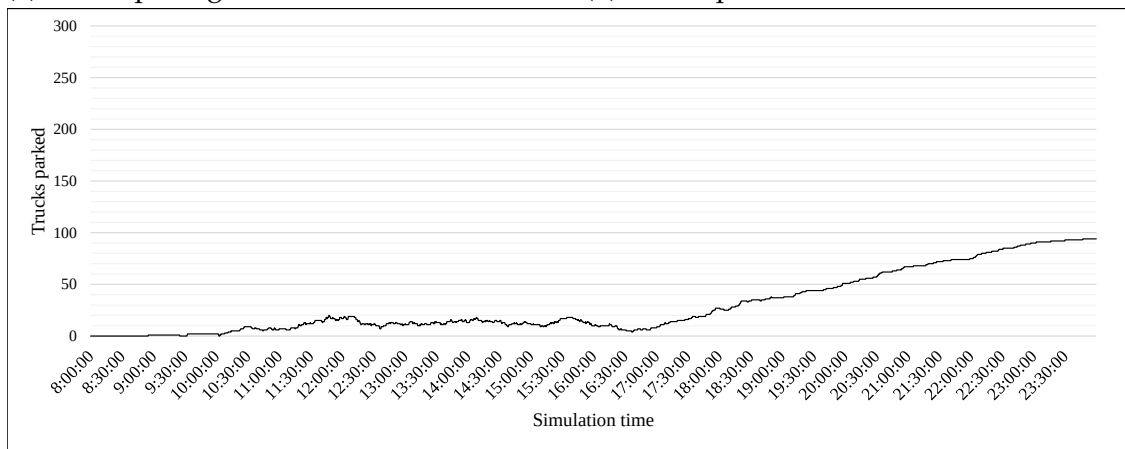
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.2.: Angola travel plaza (WB direction).

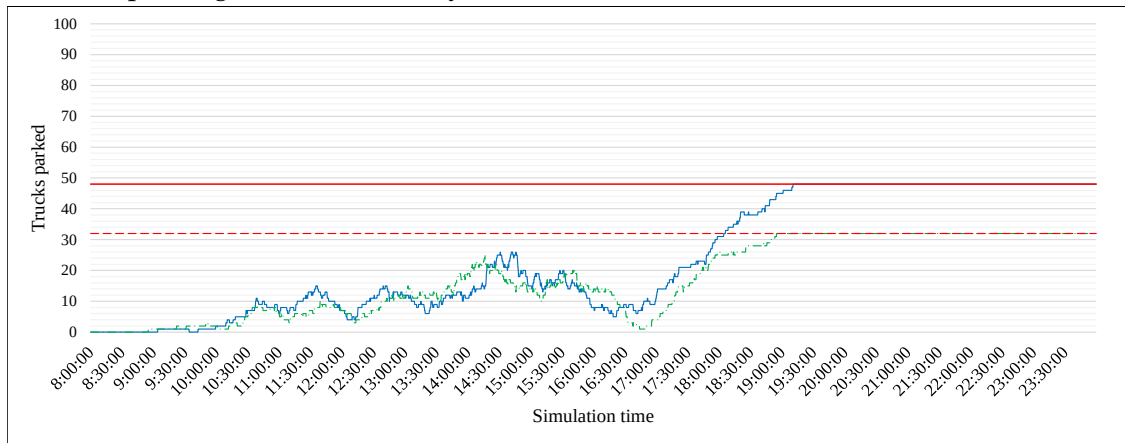


(a) Green pentagon indicates location.

(b) Aerial photo.



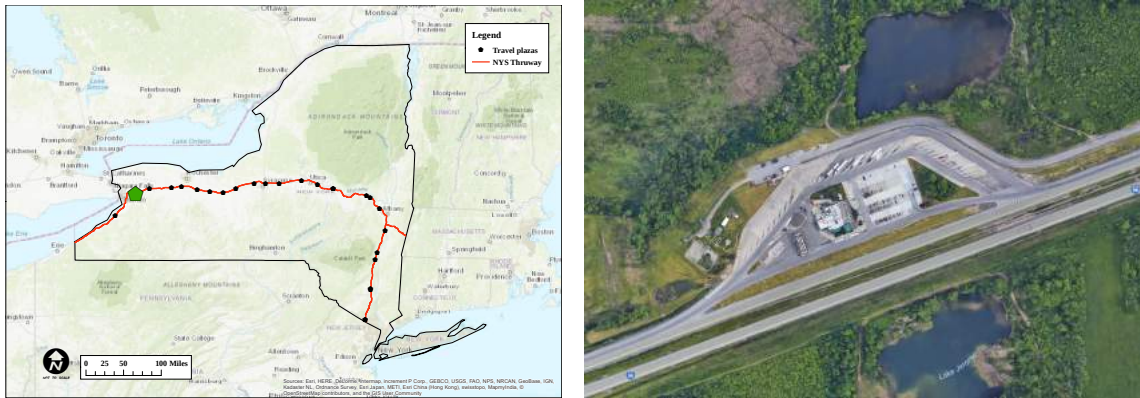
(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

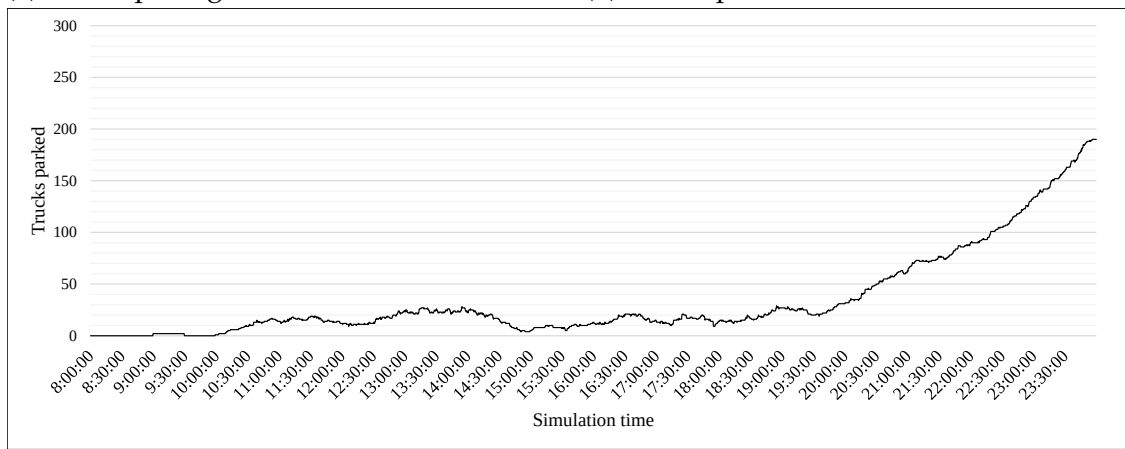
Figure D.3.: Chittenango travel plaza.



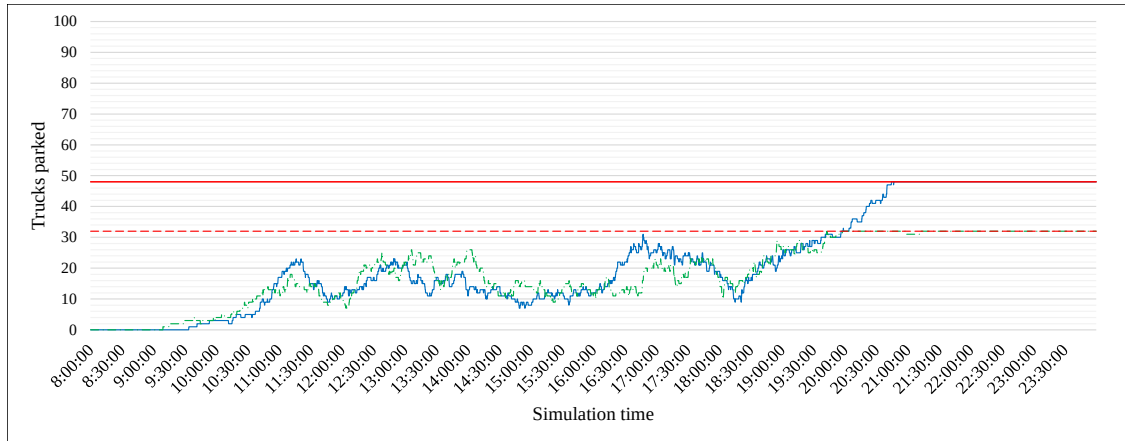


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



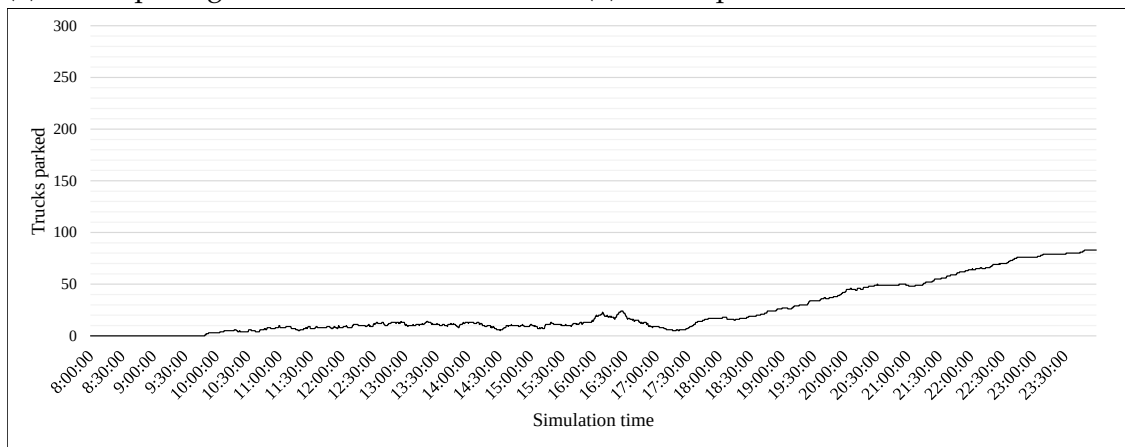
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.4.: Clarence travel plaza.

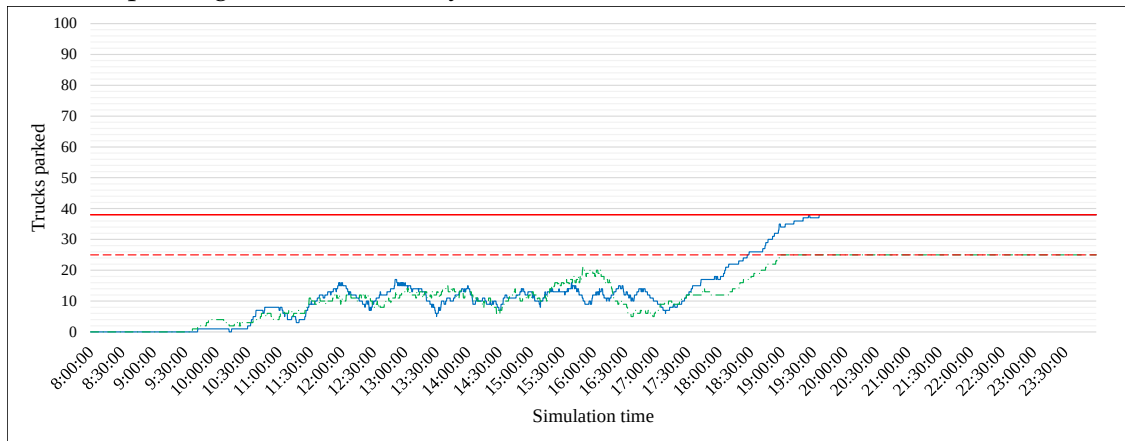


(a) Green pentagon indicates location.

(b) Aerial photo.



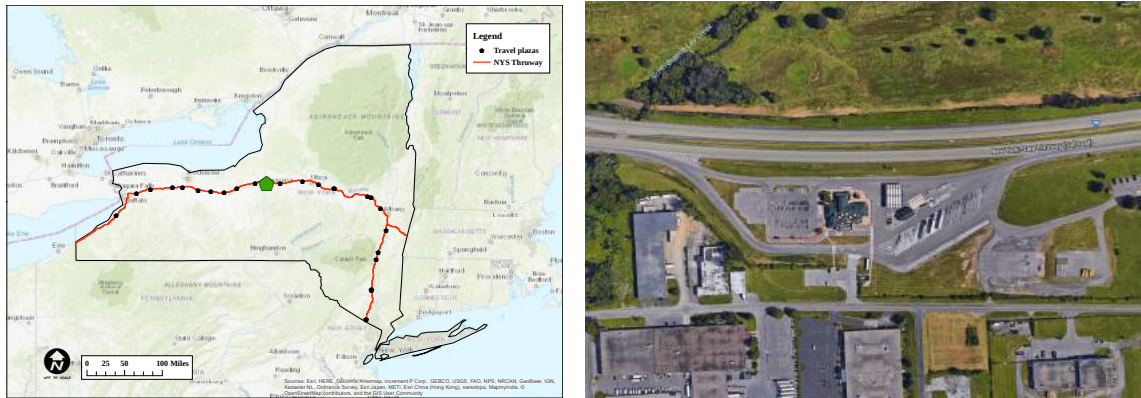
(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

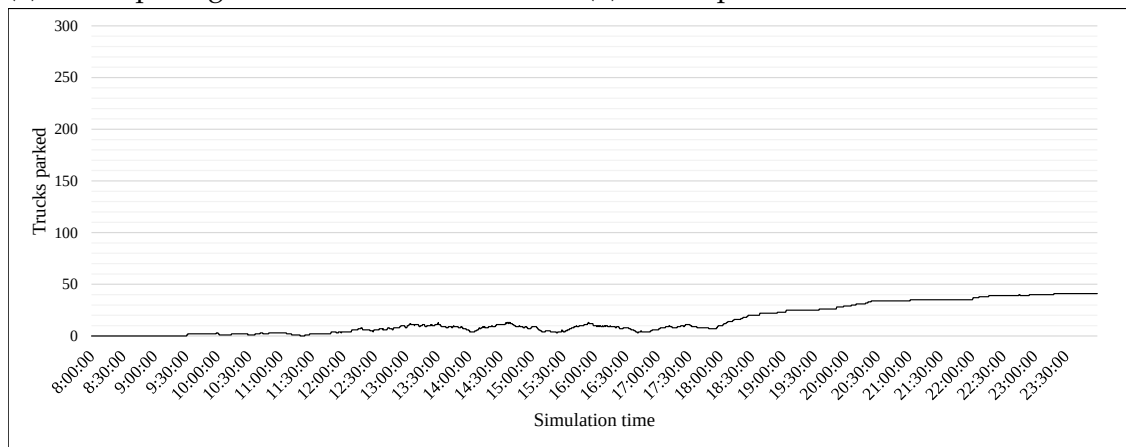
Figure D.5.: Clifton Springs travel plaza.



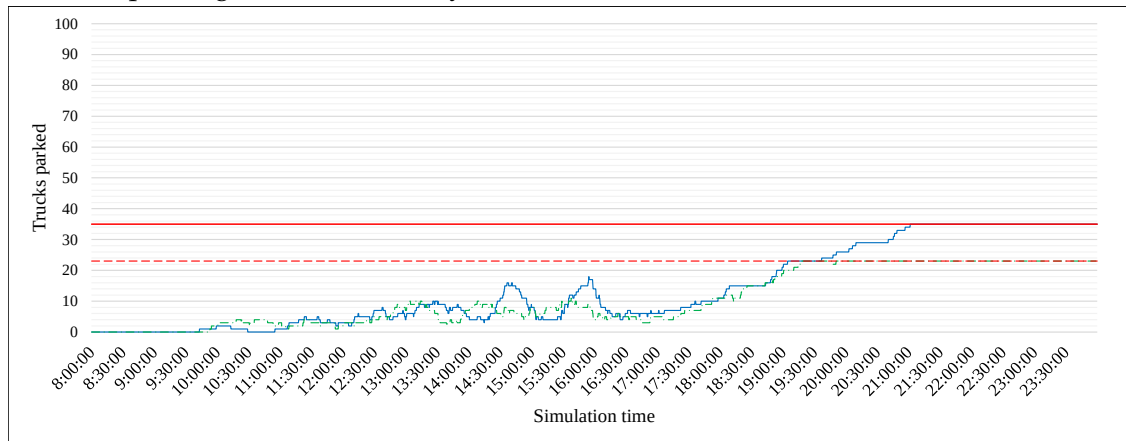


(a) Green pentagon indicates location.

(b) Aerial photo.

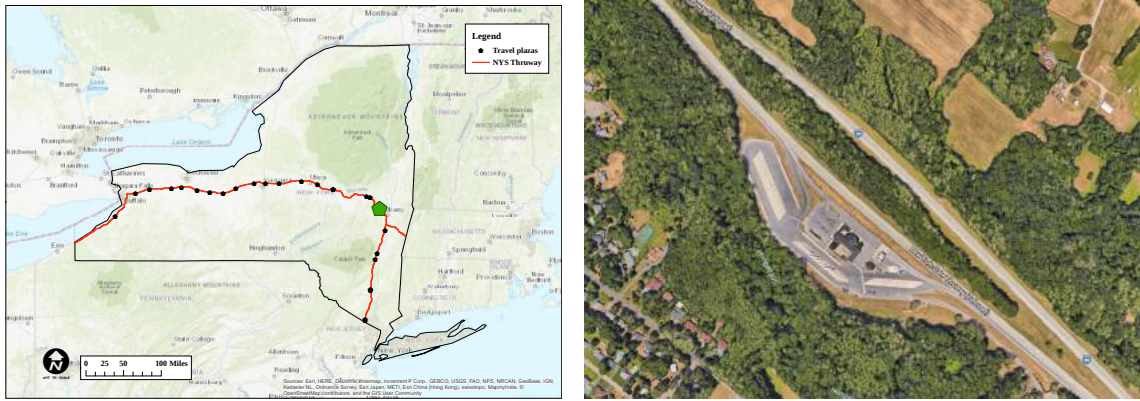


(c) Truck parking demand over day.



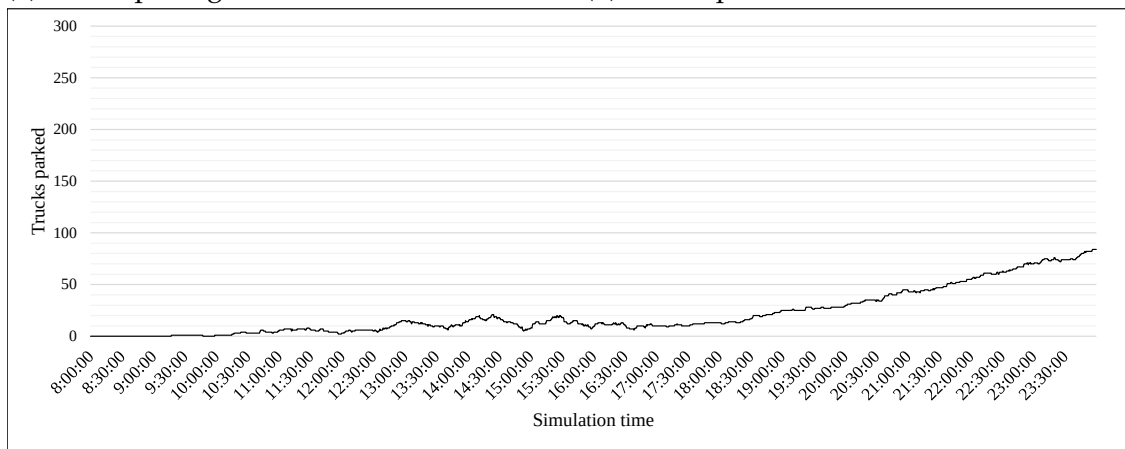
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.6.: Dewitt travel plaza.



(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

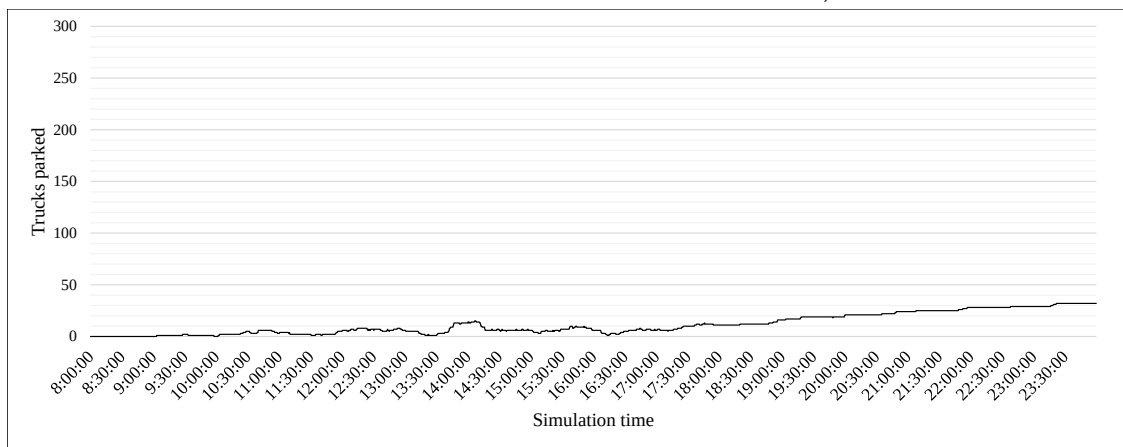
Figure D.7.: Guilderland travel plaza.



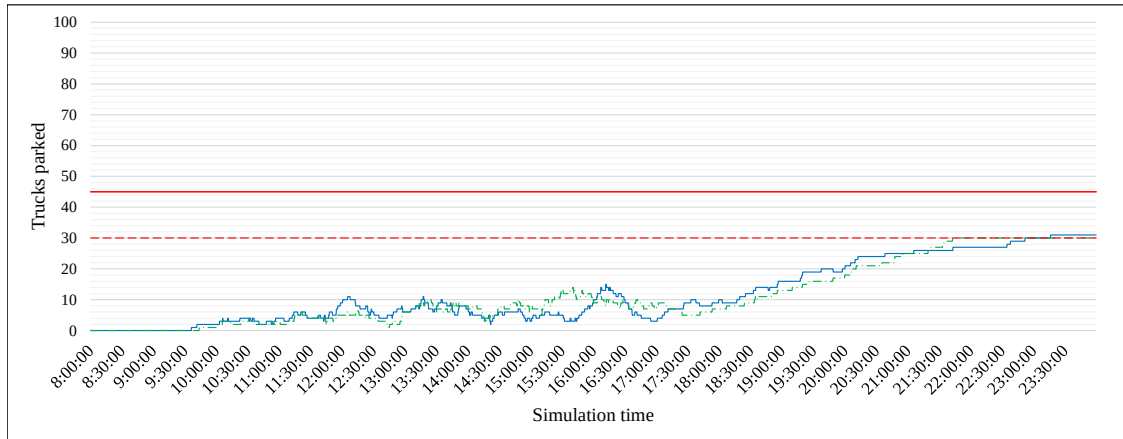
(a) Green pentagon indicates location.



(b) Aerial photo (travel plaza located on eastbound side).



(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

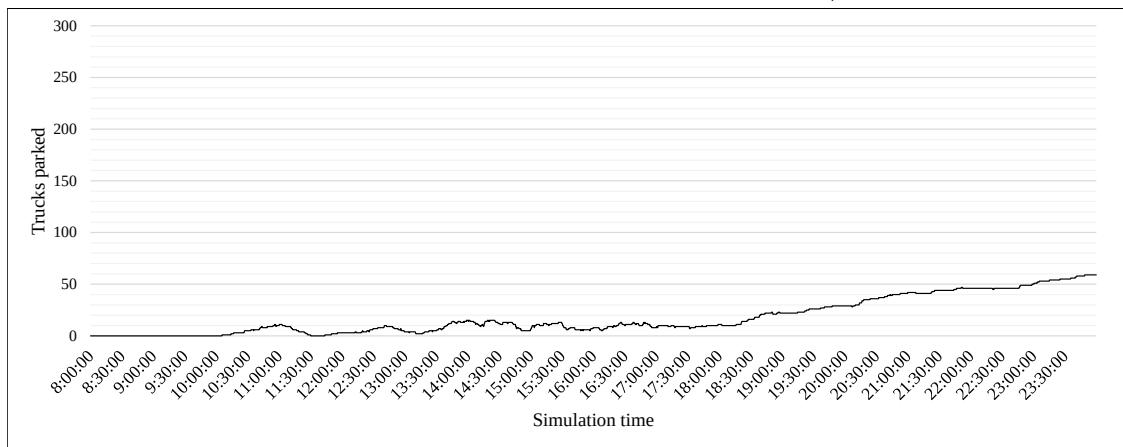
Figure D.8.: Indian Castle travel plaza.



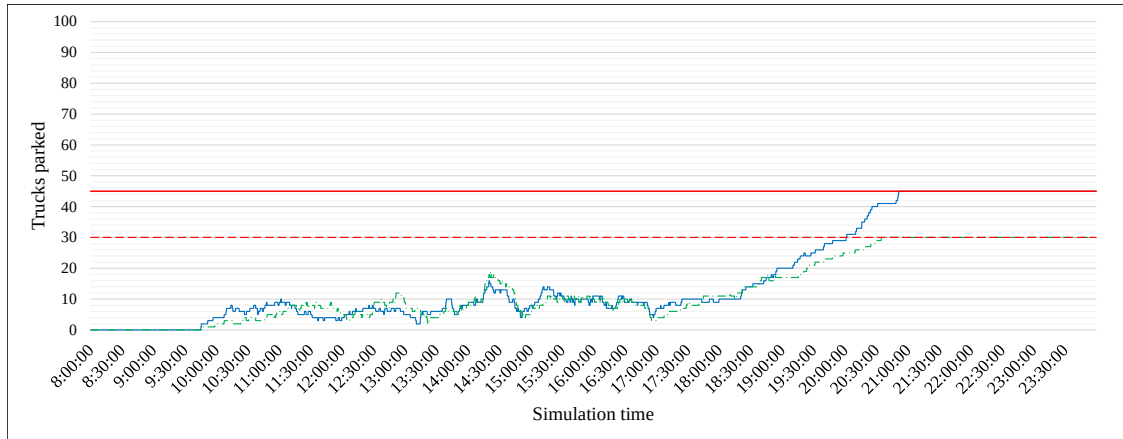
(a) Green pentagon indicates location.



(b) Aerial photo (travel plaza located on westbound side).



(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

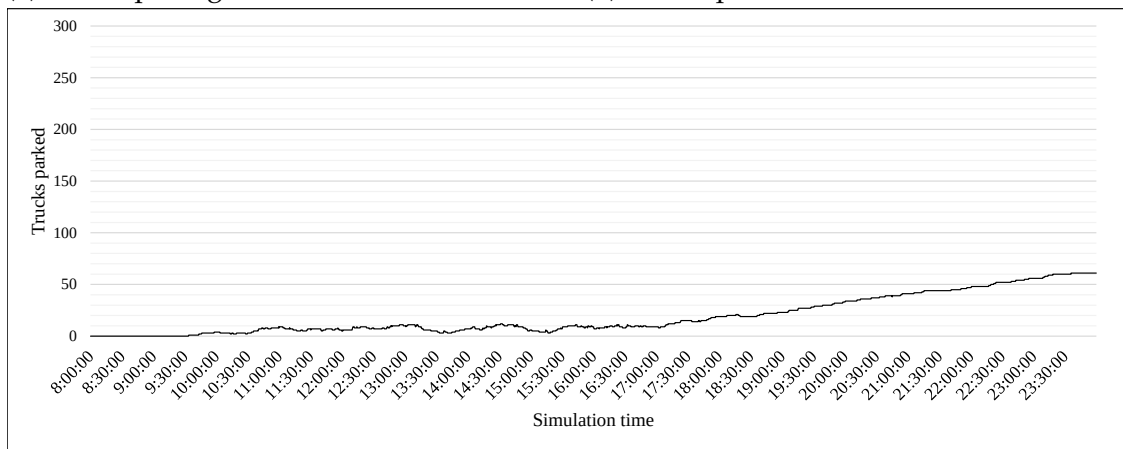
Figure D.9.: Iroquois travel plaza.



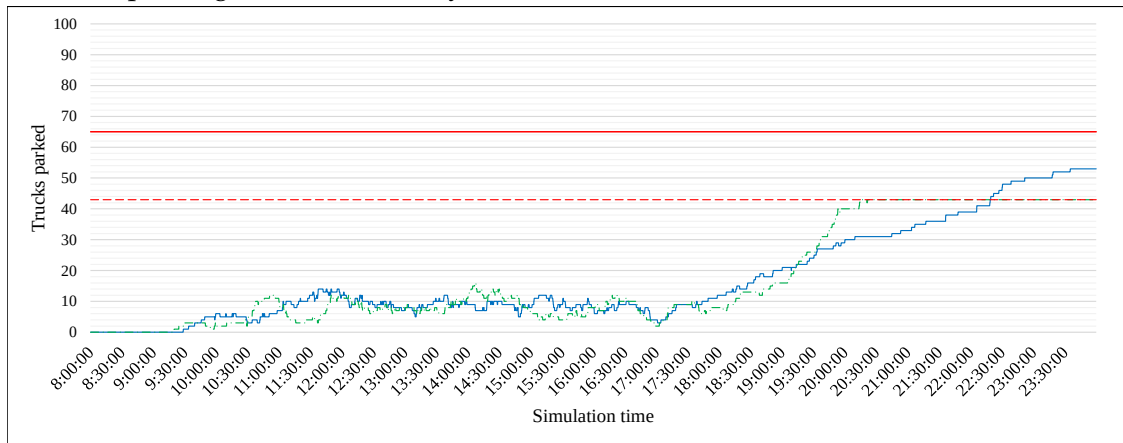


(a) Green pentagon indicates location.

(b) Aerial photo.

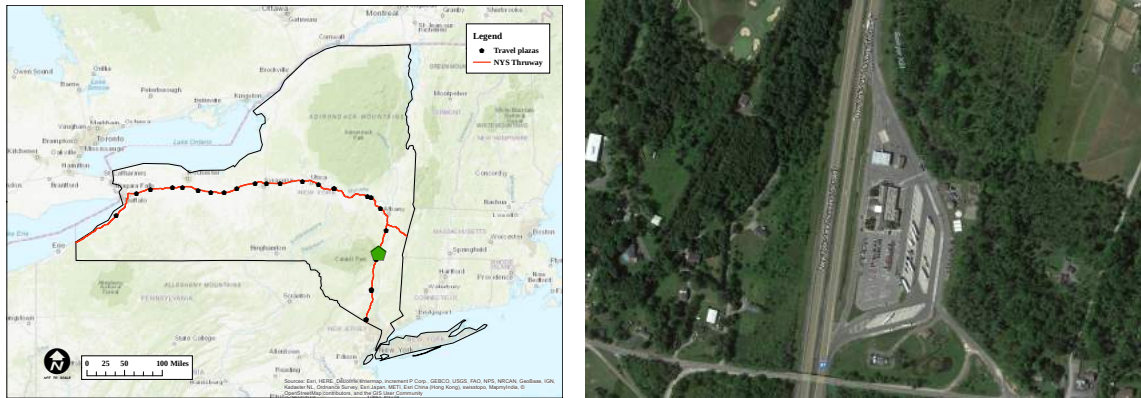


(c) Truck parking demand over day.



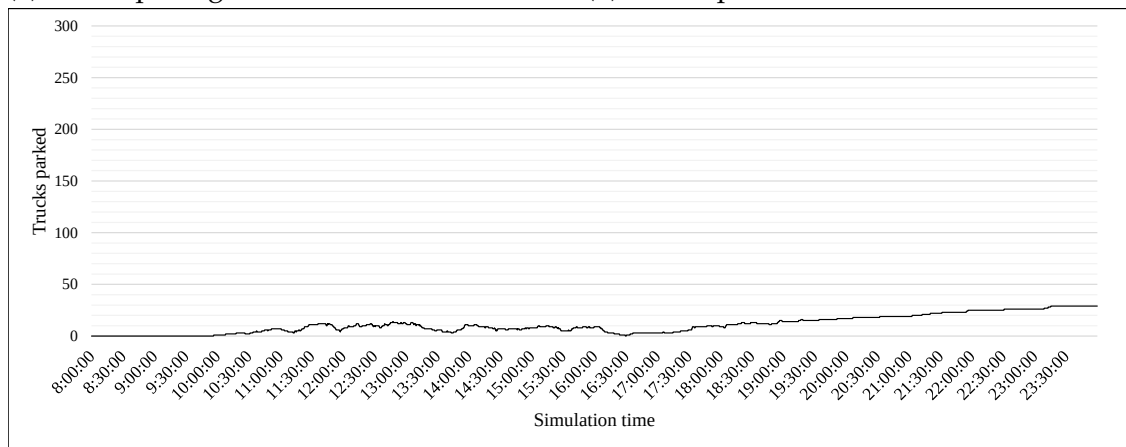
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.10.: Junius Ponds travel plaza.

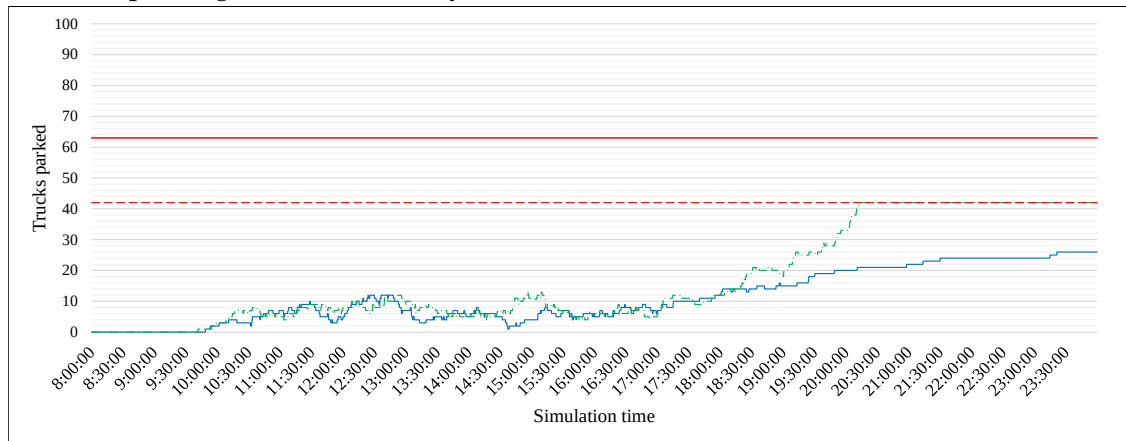


(a) Green pentagon indicates location.

(b) Aerial photo.

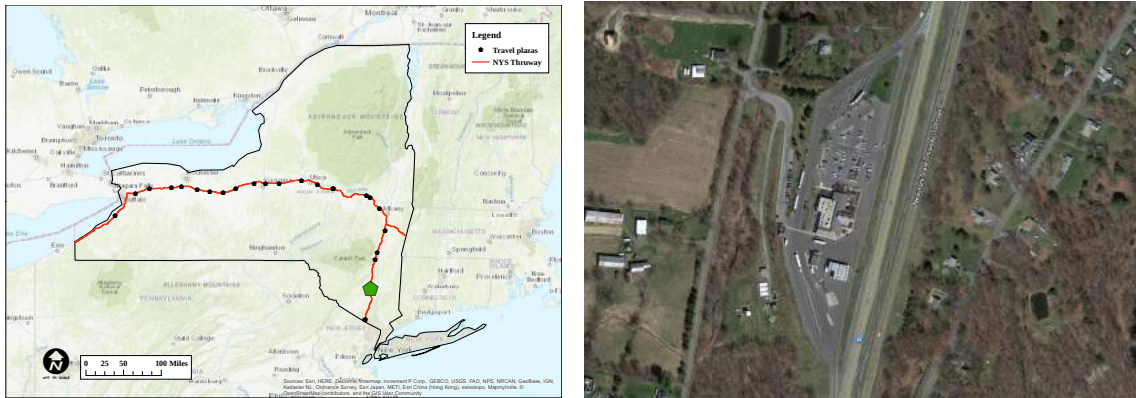


(c) Truck parking demand over day.



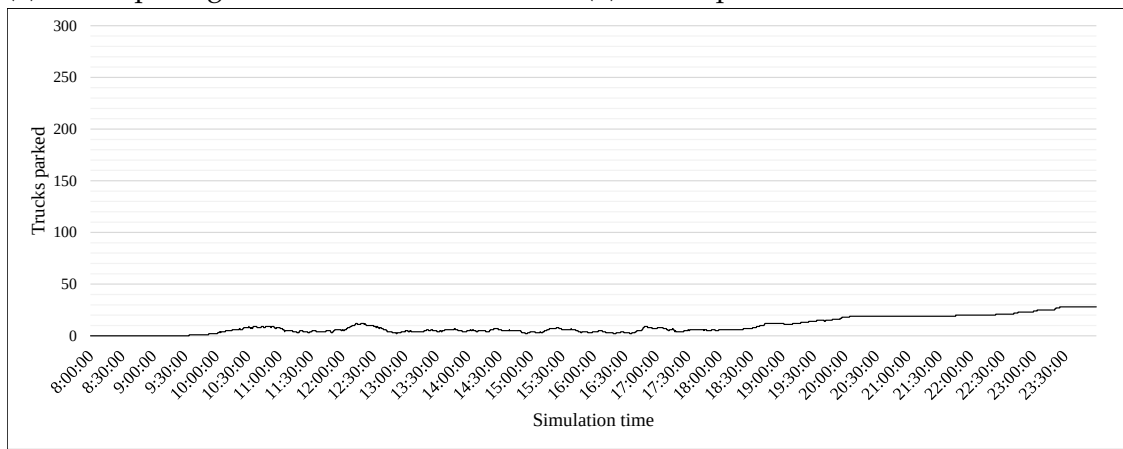
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.11.: Malden travel plaza.

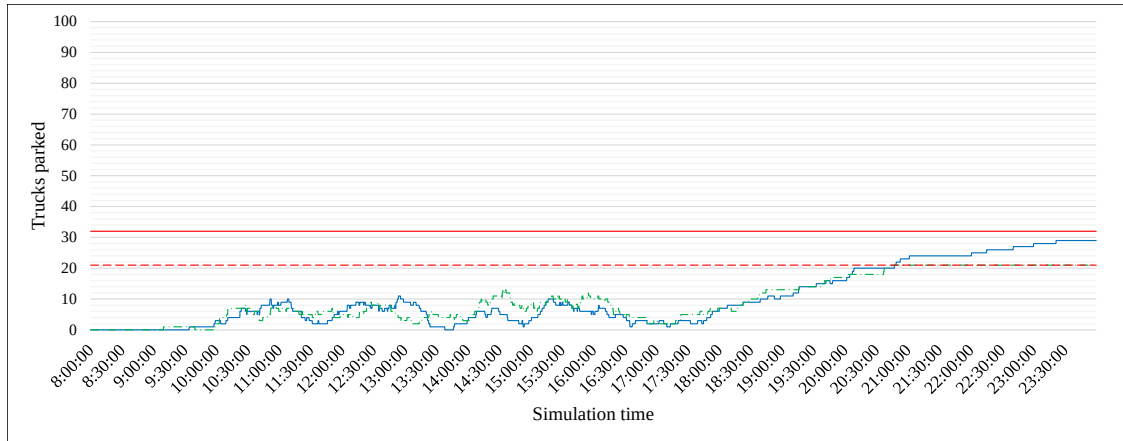


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



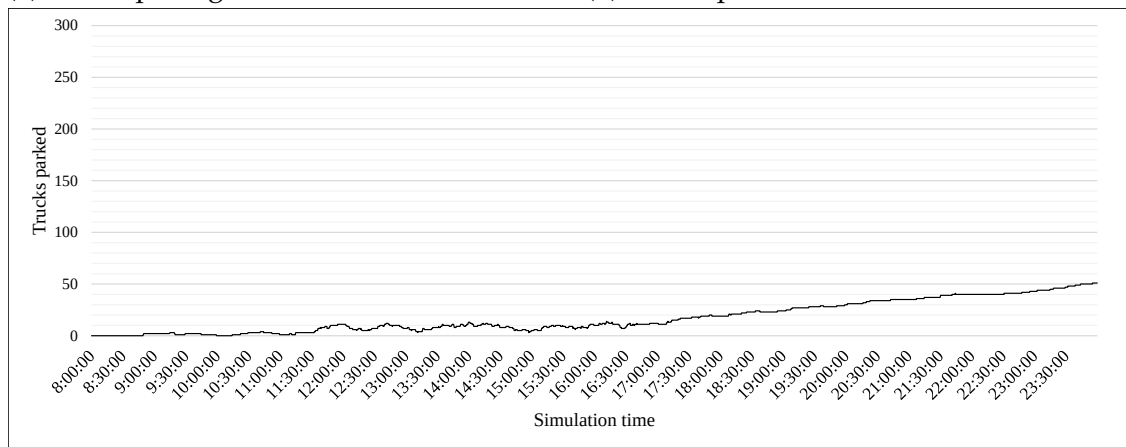
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.12.: Modena travel plaza.

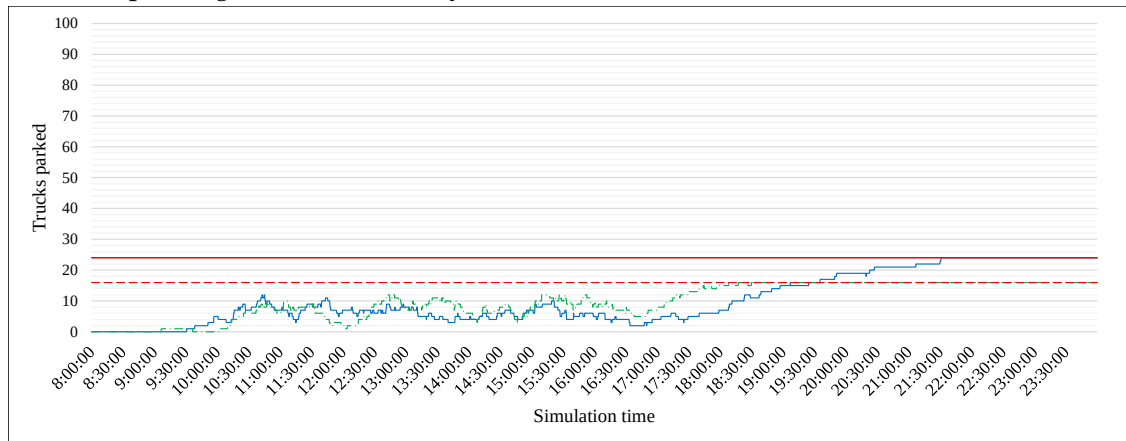


(a) Green pentagon indicates location.

(b) Aerial photo.



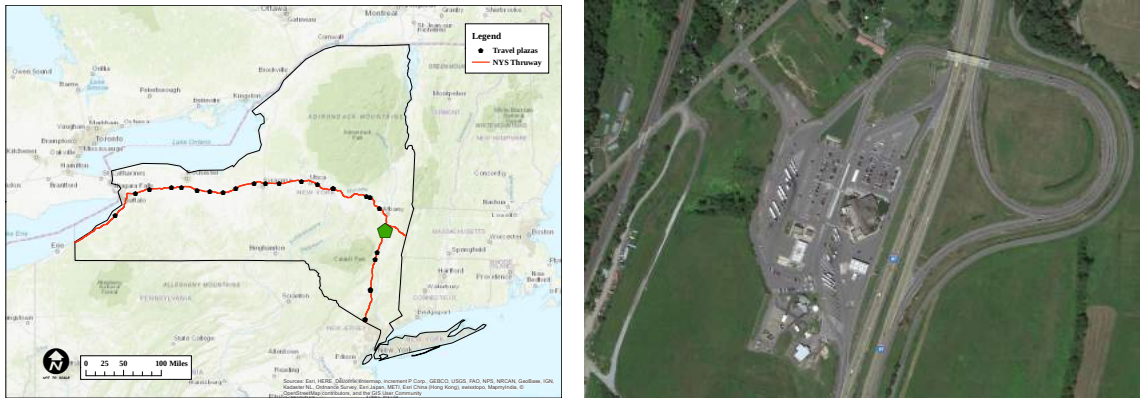
(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

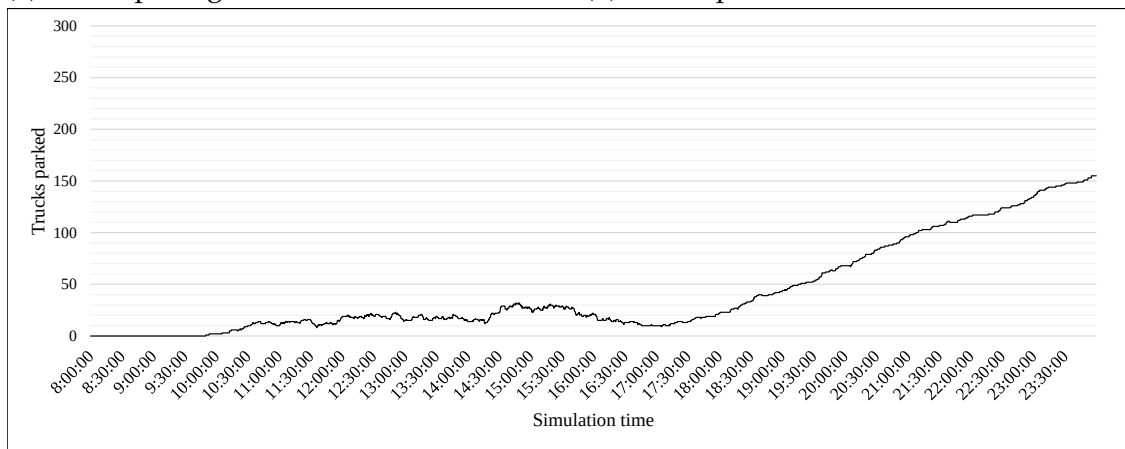
Figure D.13.: Mohawk travel plaza.



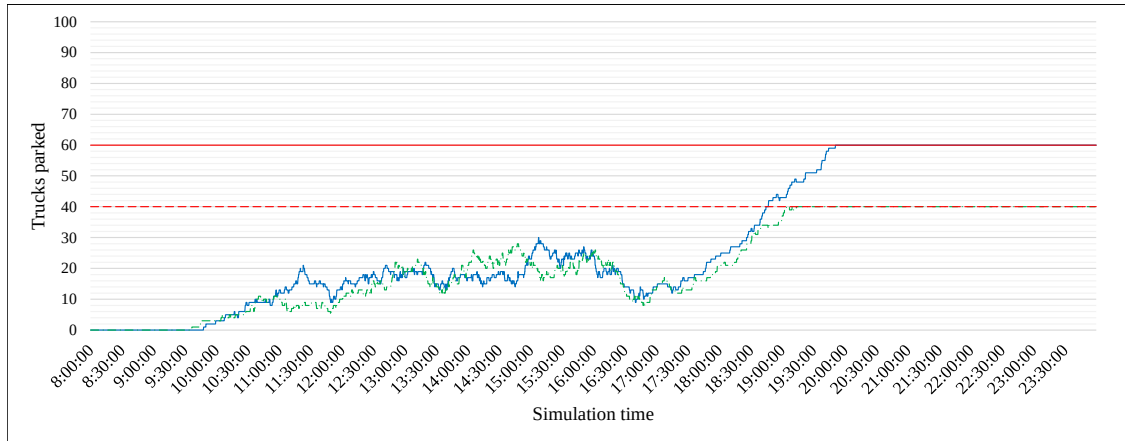


(a) Green pentagon indicates location.

(b) Aerial photo.

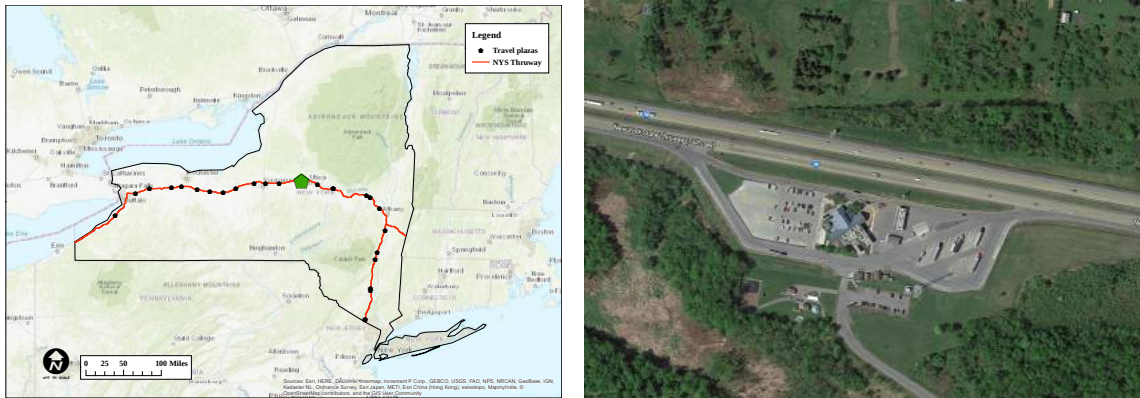


(c) Truck parking demand over day.



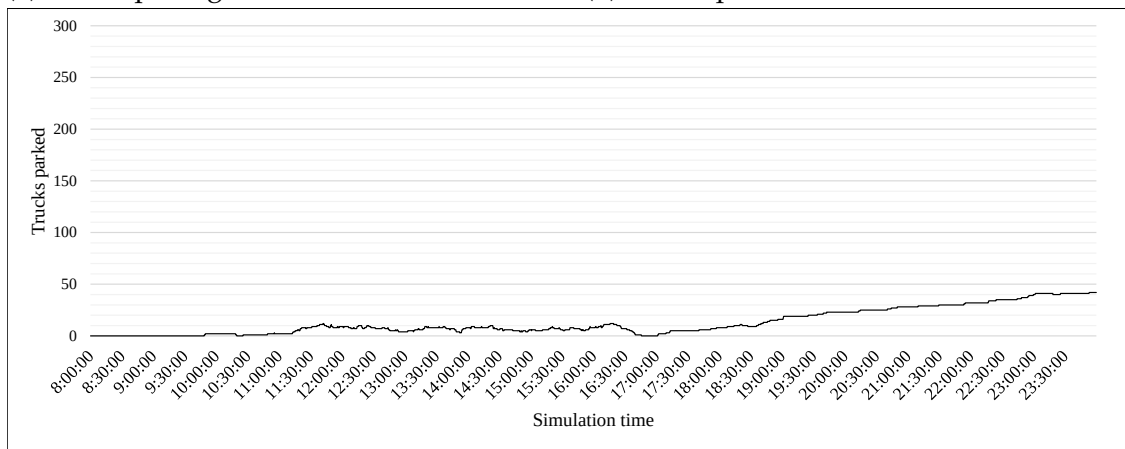
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.14.: New Baltimore travel plaza.

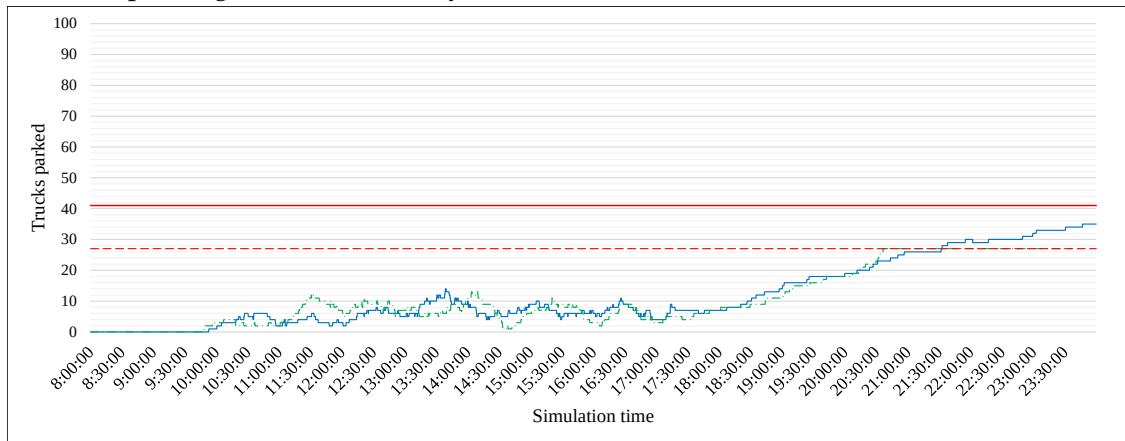


(a) Green pentagon indicates location.

(b) Aerial photo.

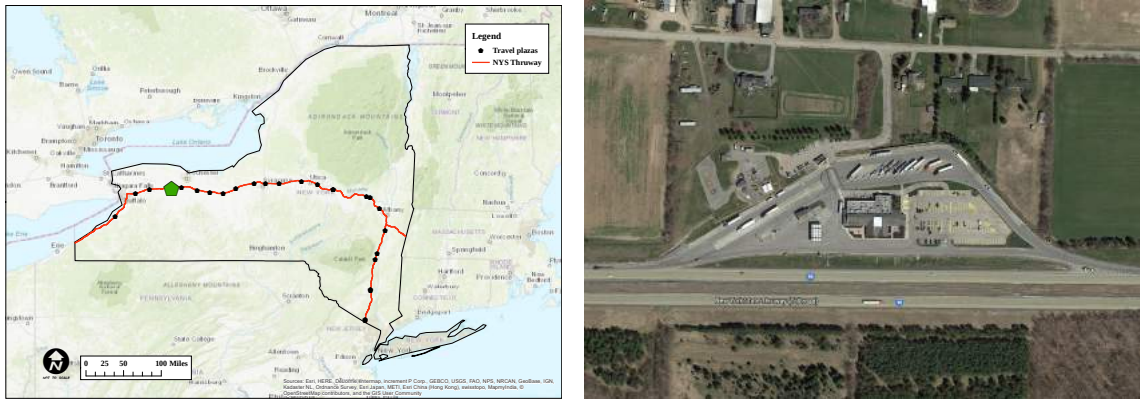


(c) Truck parking demand over day.



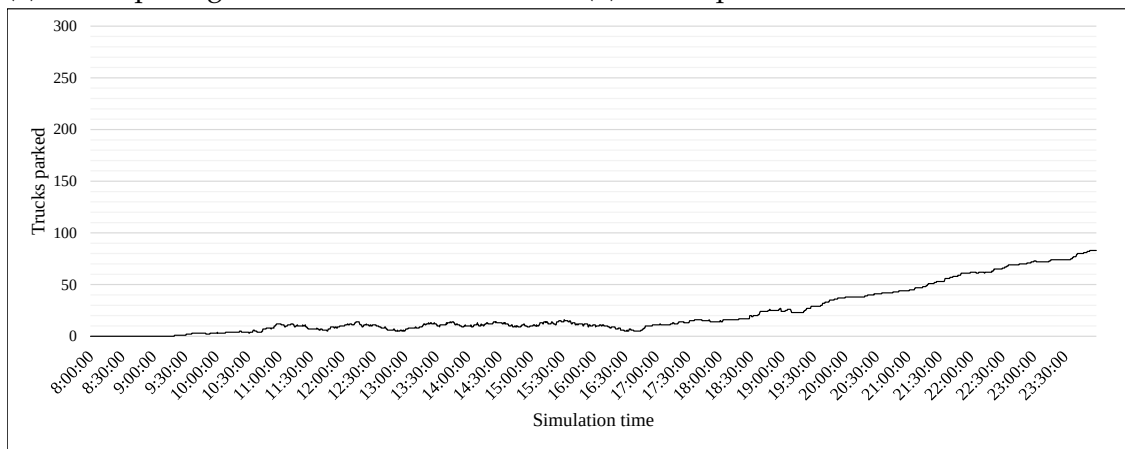
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.15.: Oneida travel plaza.

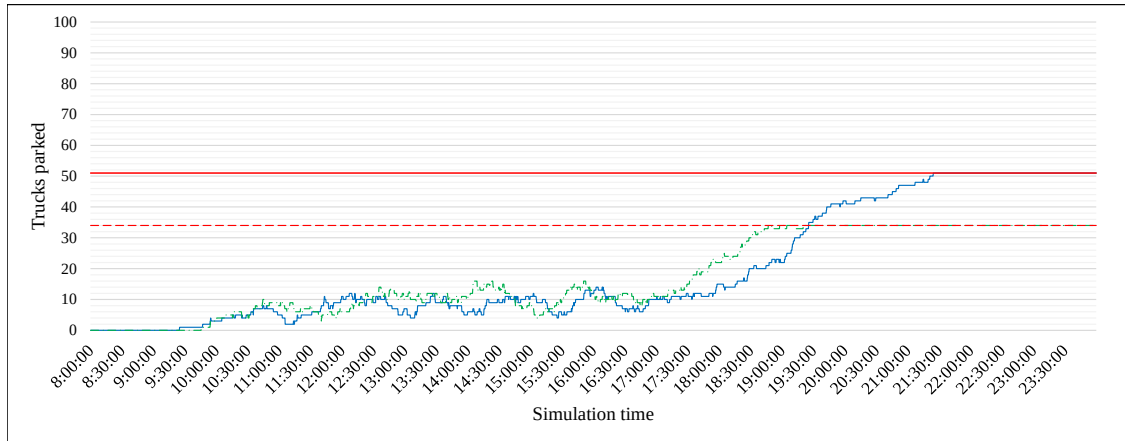


(a) Green pentagon indicates location.

(b) Aerial photo.

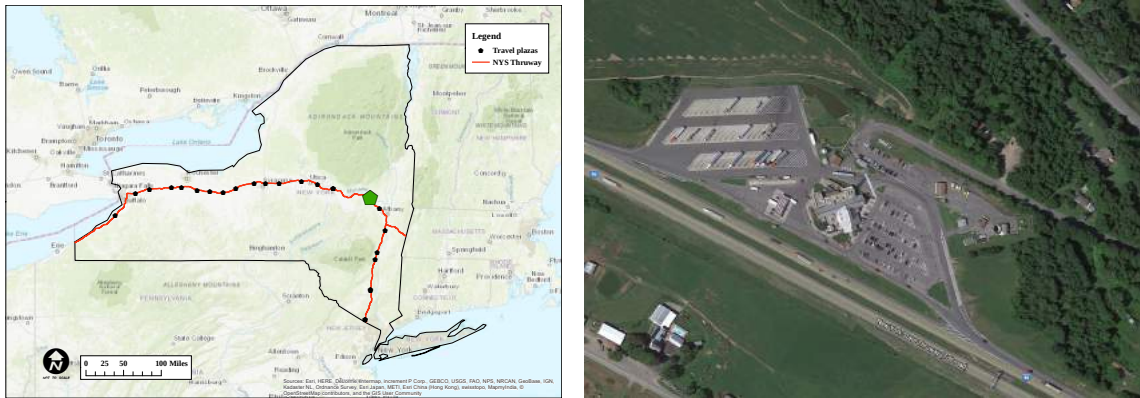


(c) Truck parking demand over day.



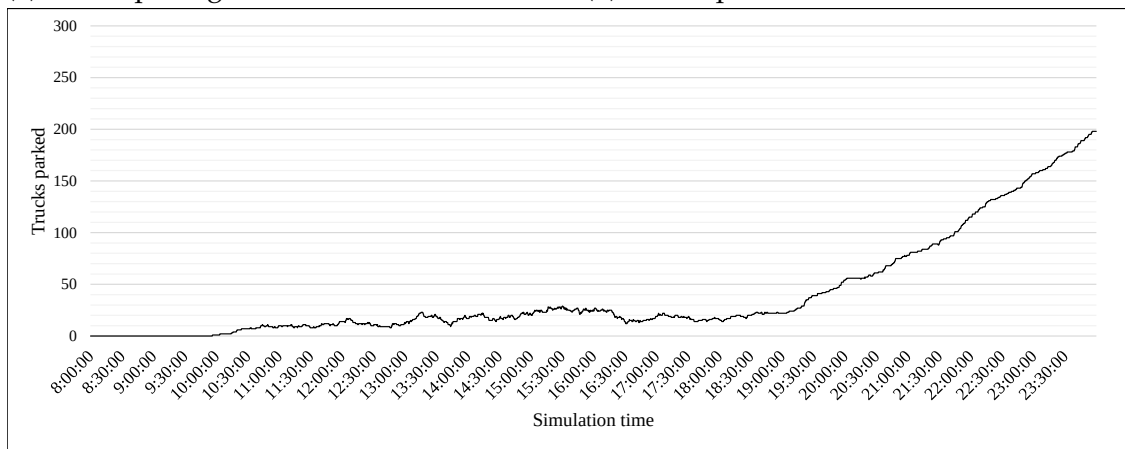
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.16.: Ontario travel plaza.

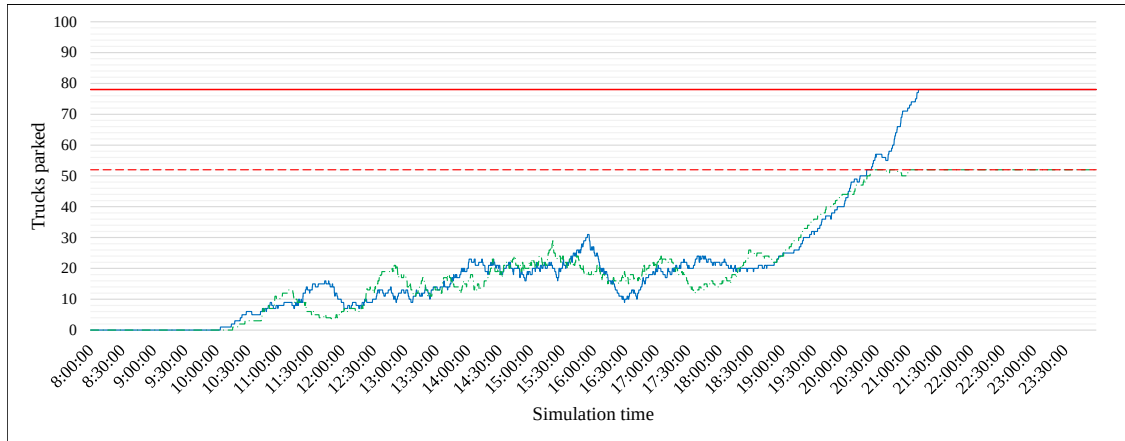


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

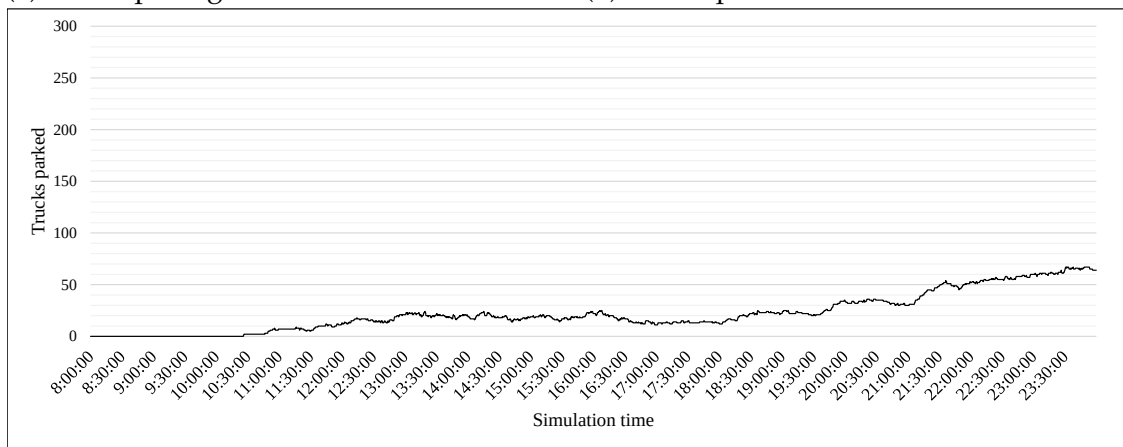
Figure D.17.: Pattersonville travel plaza.



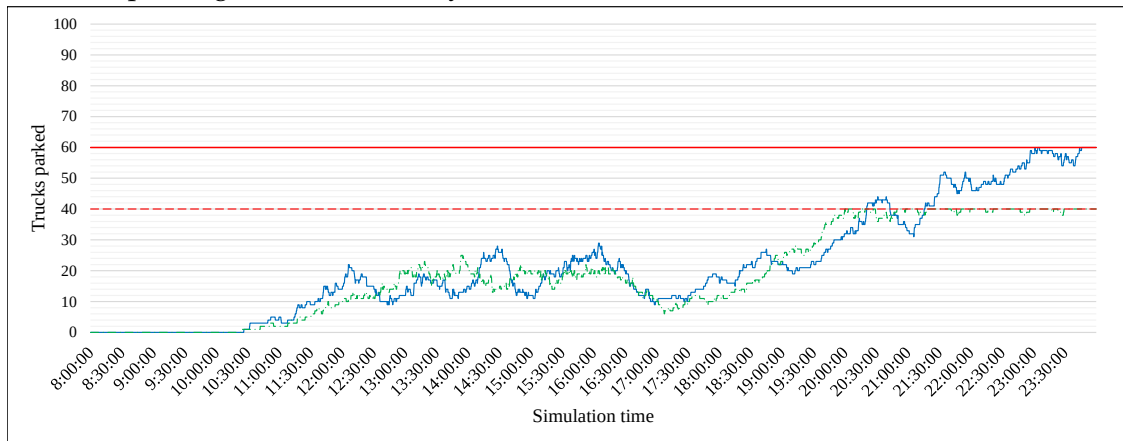


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



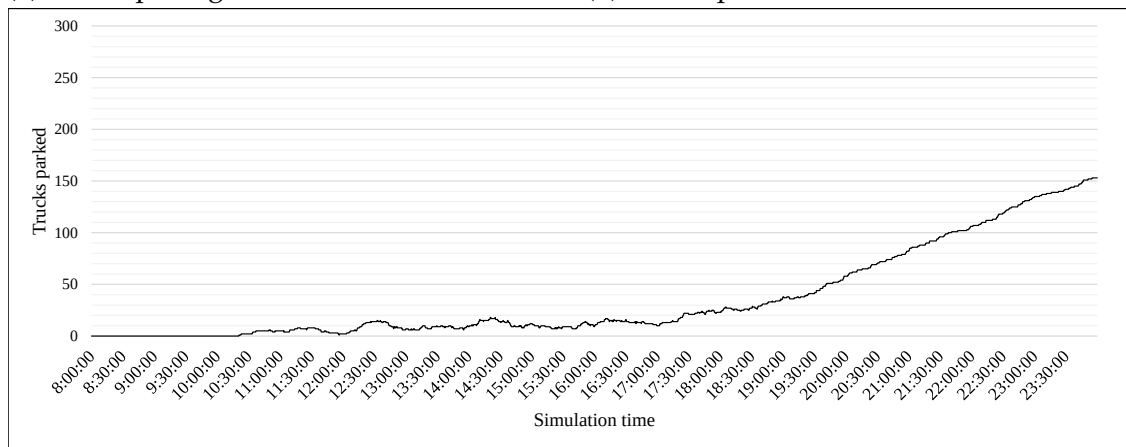
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.18.: Pembroke travel plaza.

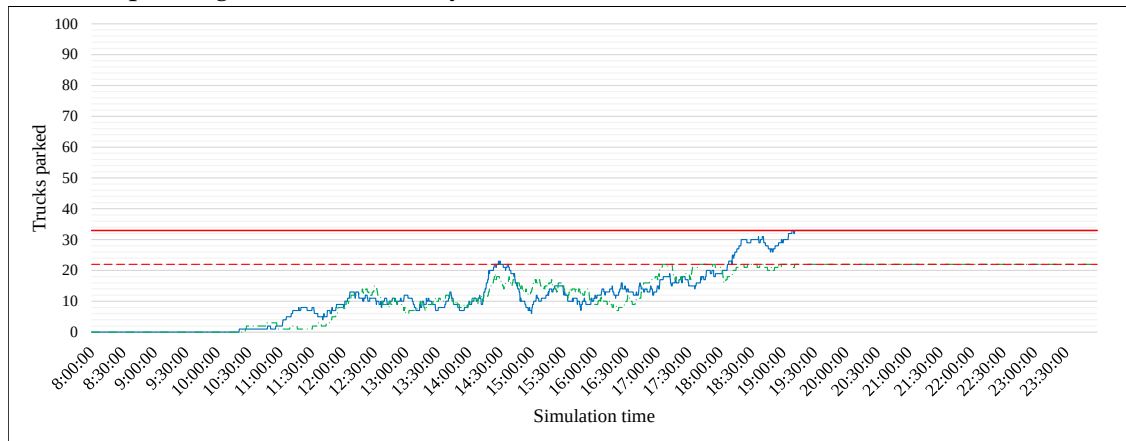


(a) Green pentagon indicates location.

(b) Aerial photo.

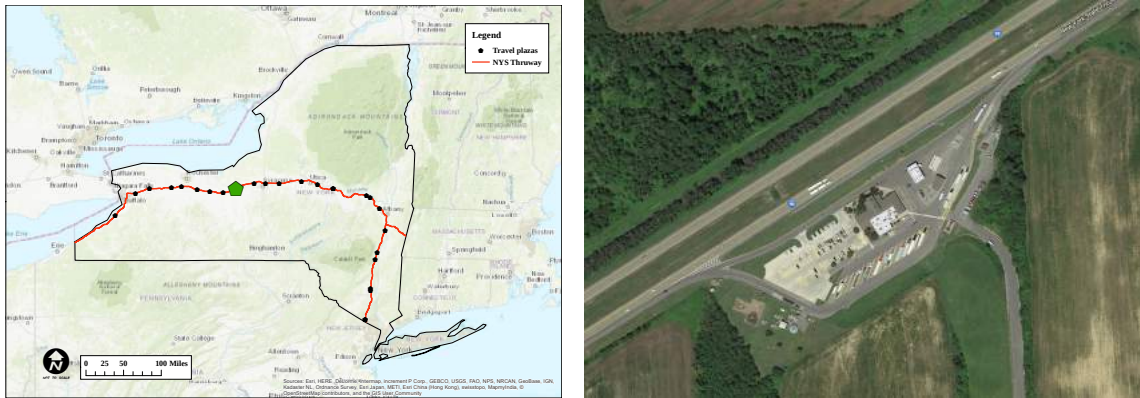


(c) Truck parking demand over day.



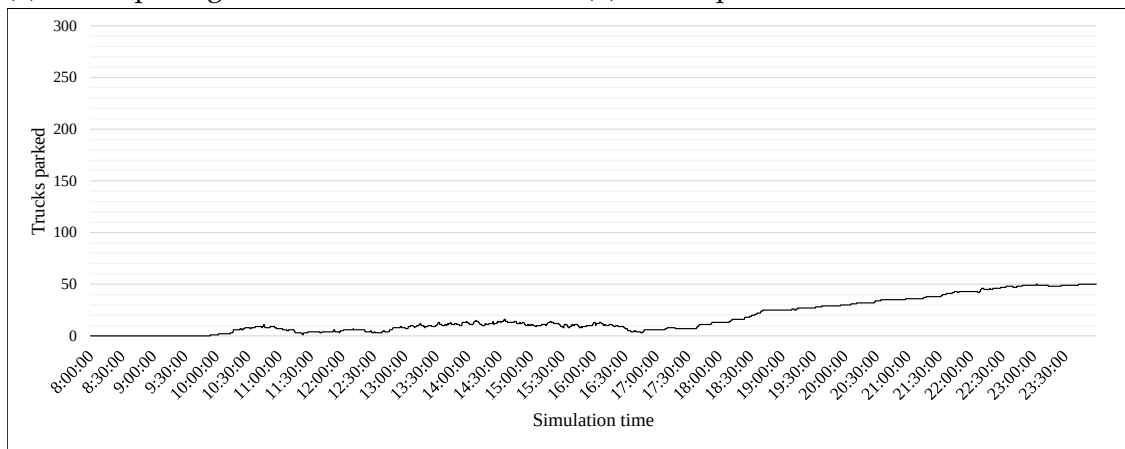
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.19.: Plattekill travel plaza.

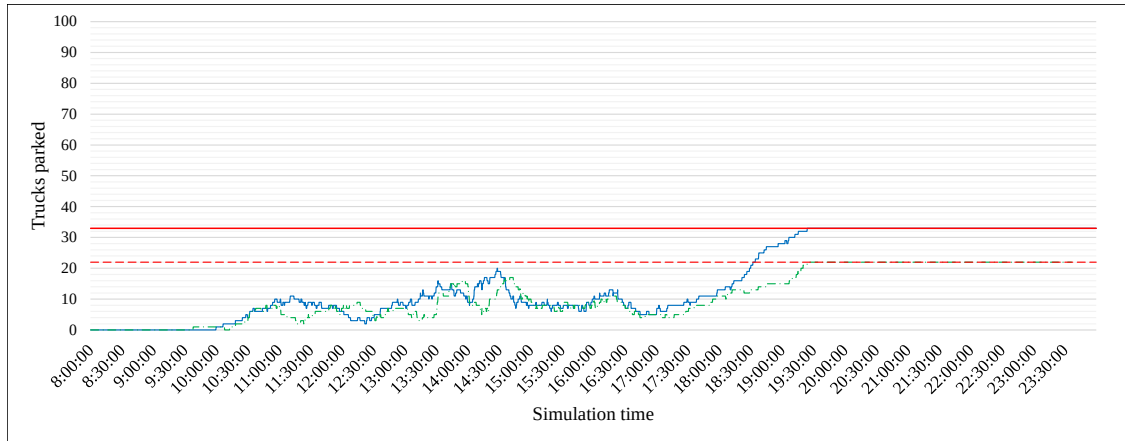


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



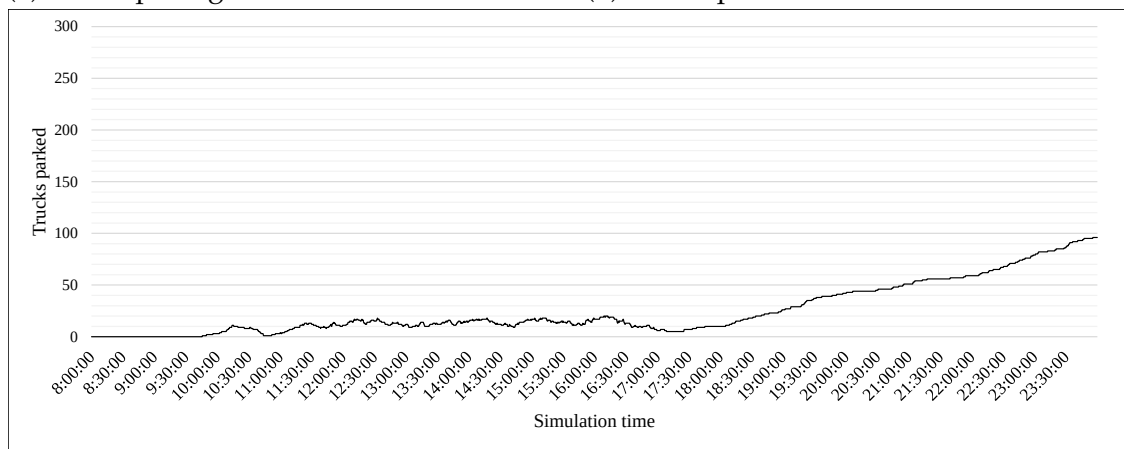
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.20.: Port Byron travel plaza.

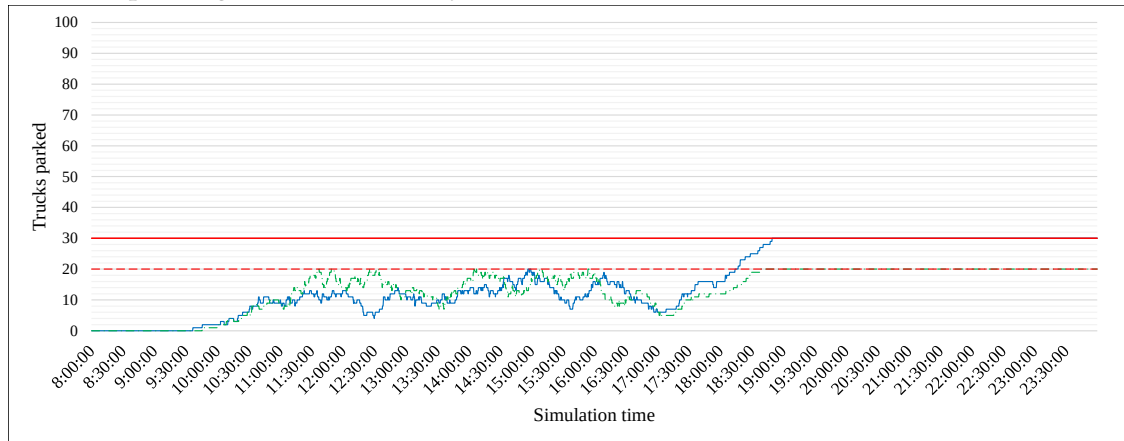


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

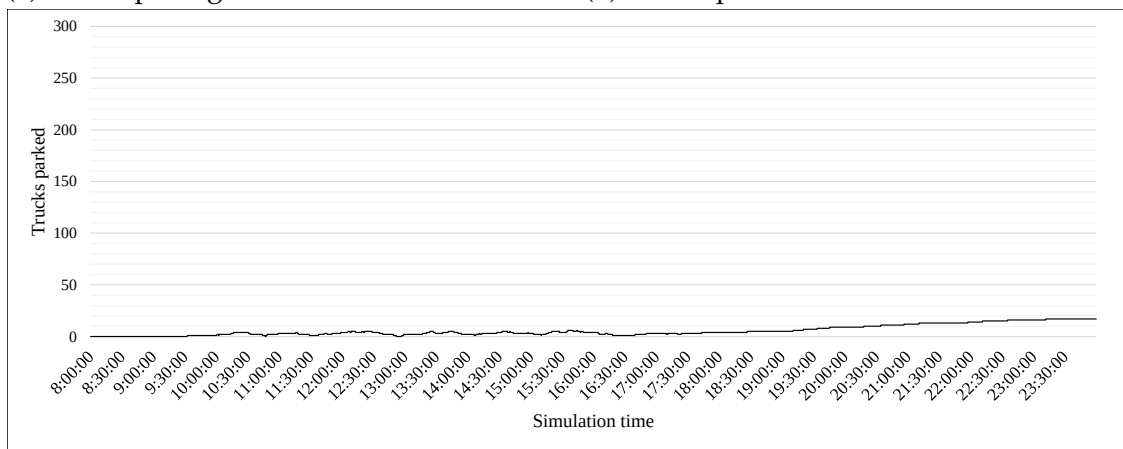
Figure D.21.: Ramapo travel plaza.



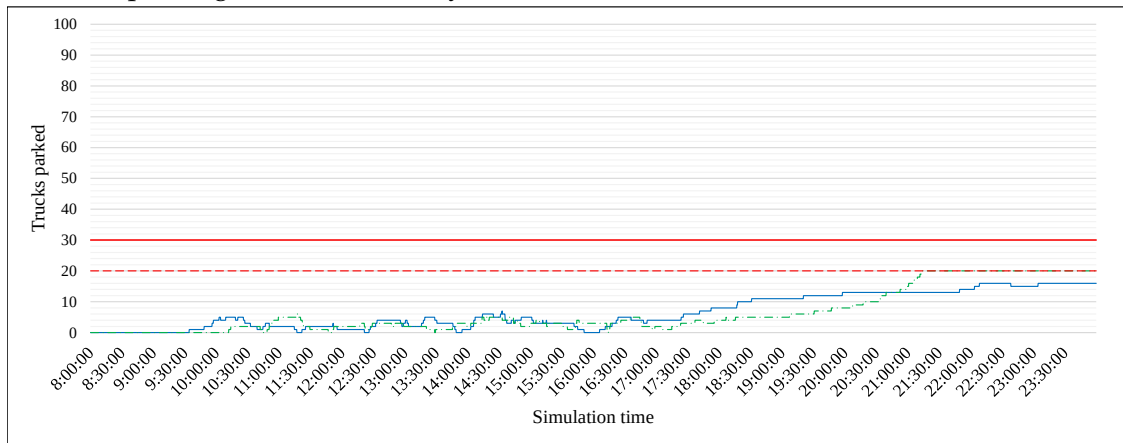


(a) Green pentagon indicates location.

(b) Aerial photo.

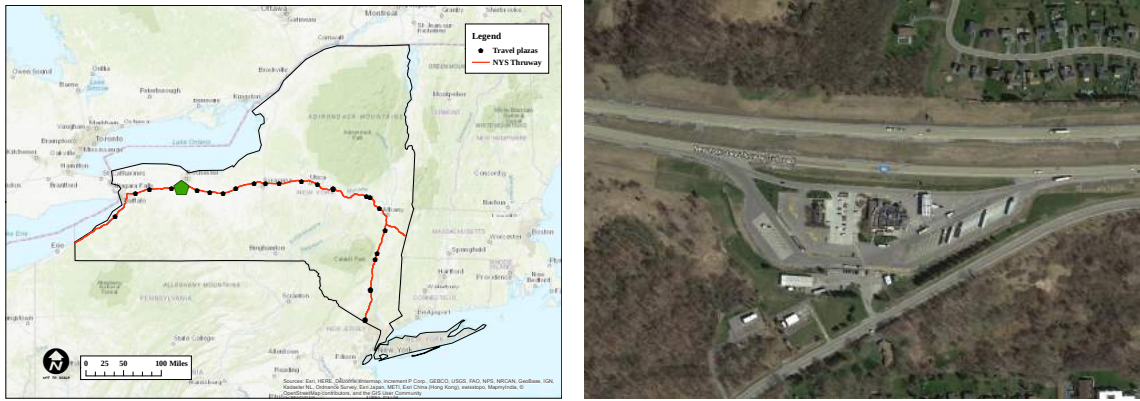


(c) Truck parking demand over day.



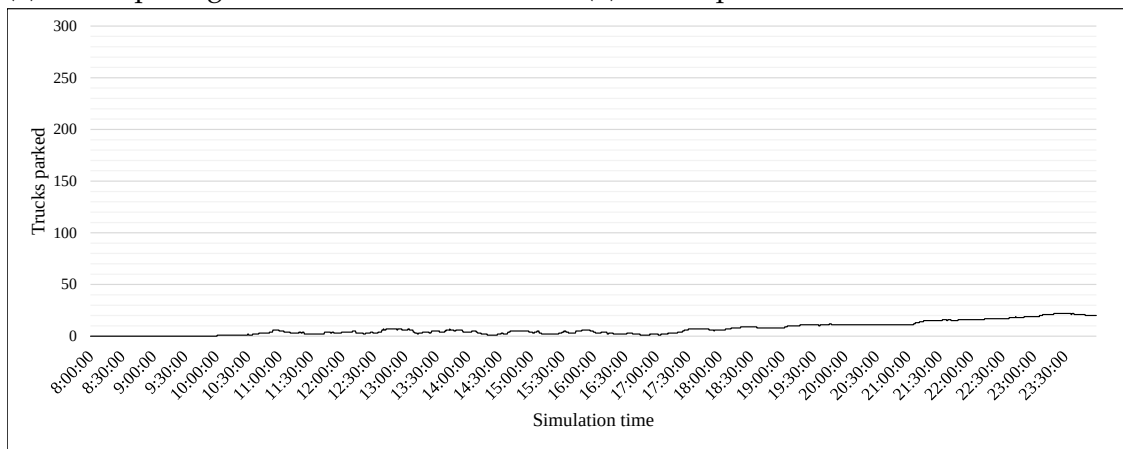
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.22.: Schuyler travel plaza.

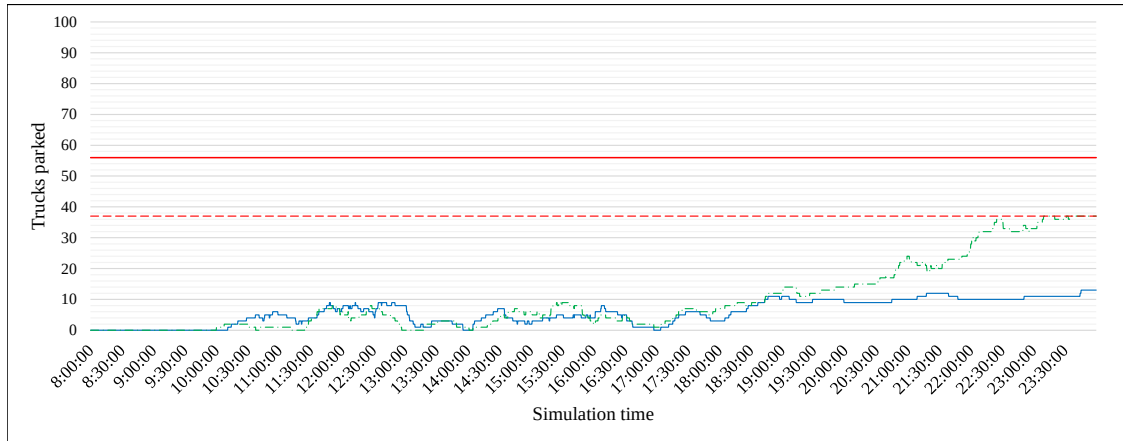


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



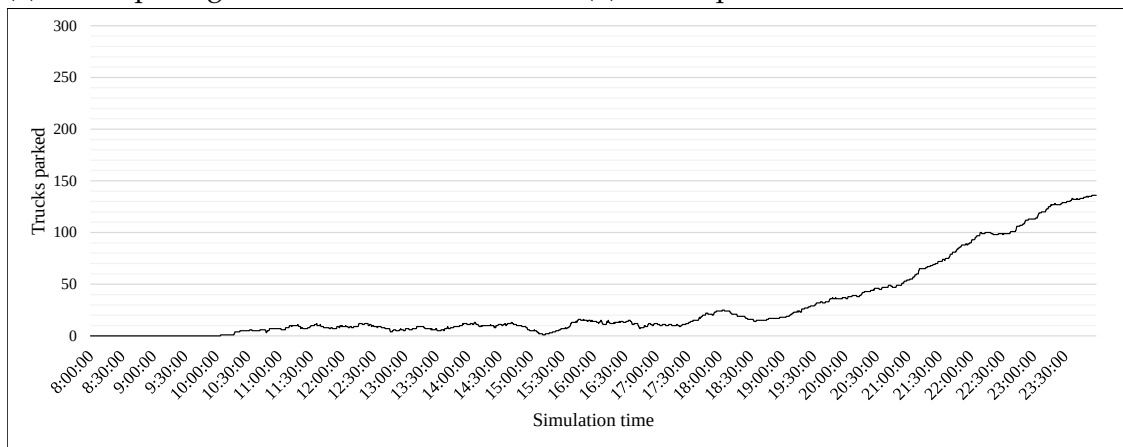
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.23.: Scottsville travel plaza.

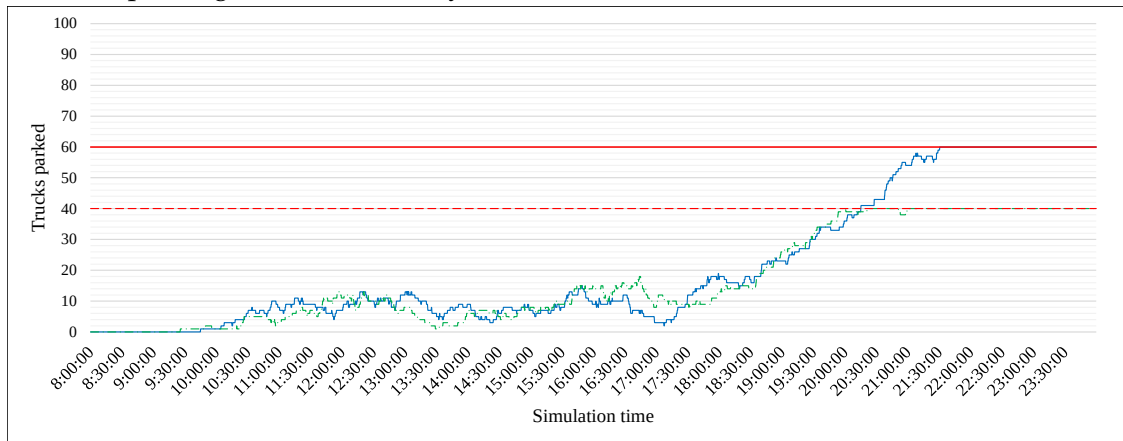


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



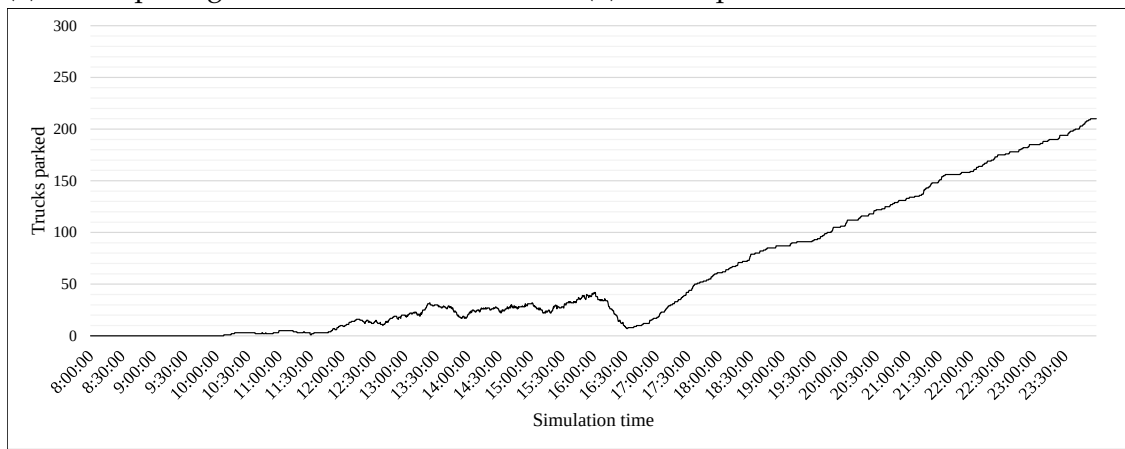
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.24.: Seneca travel plaza.

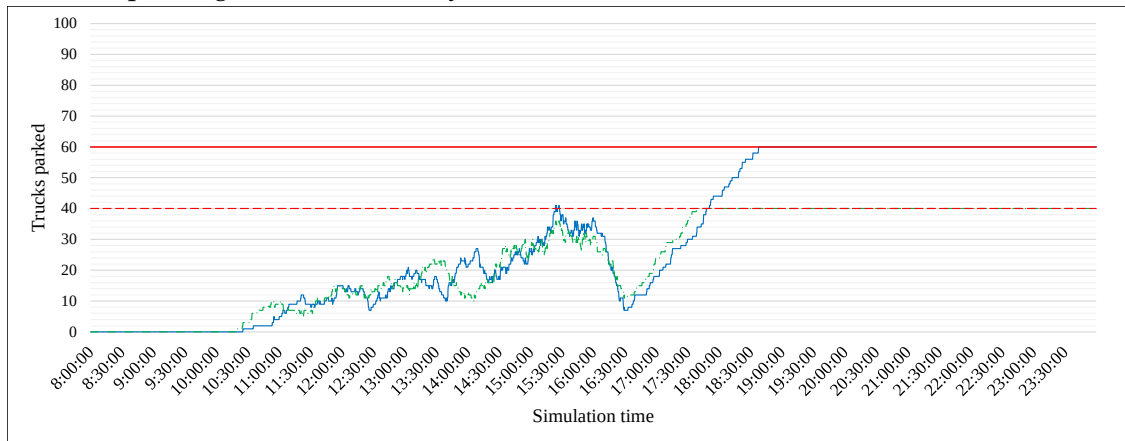


(a) Green pentagon indicates location.

(b) Aerial photo.

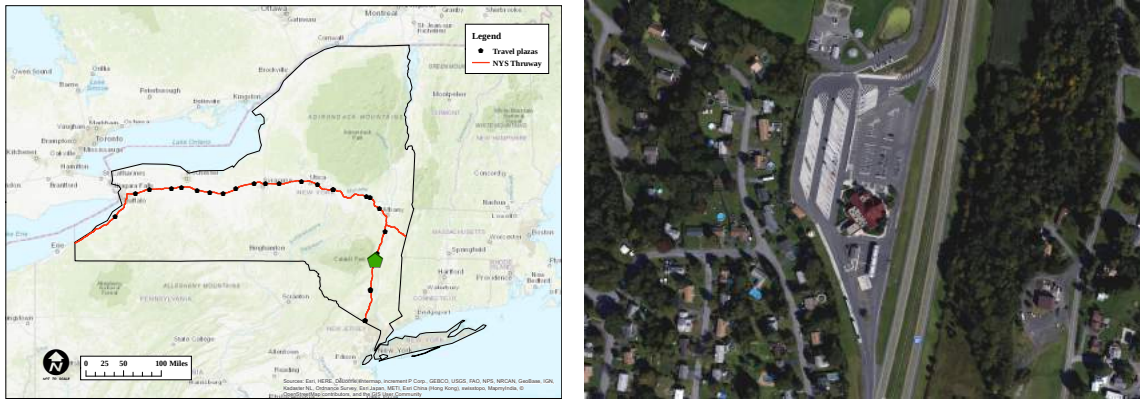


(c) Truck parking demand over day.



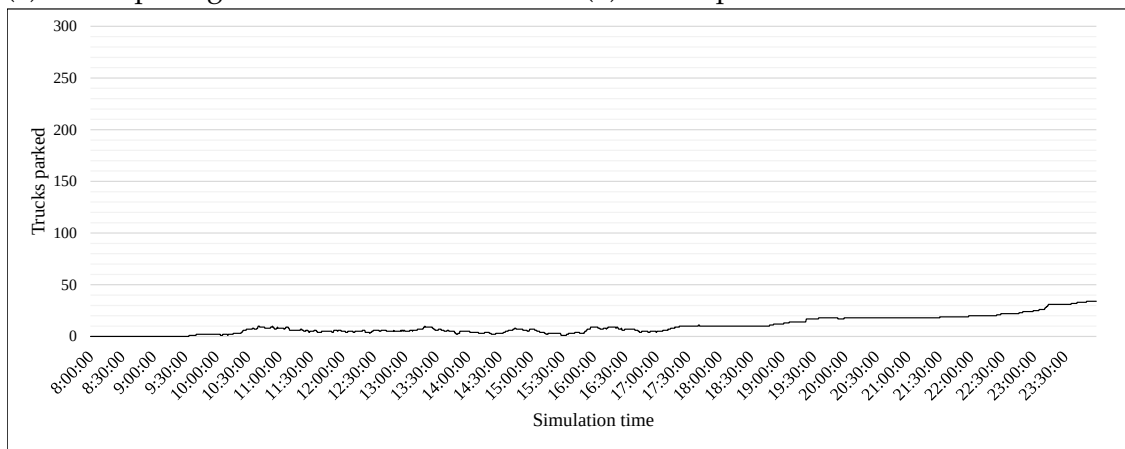
(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.25.: Sloatsburg travel plaza.

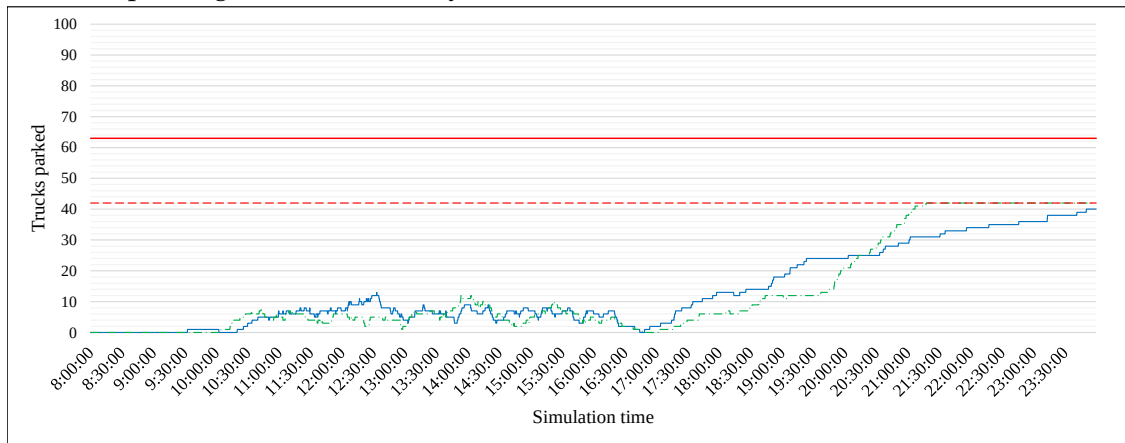


(a) Green pentagon indicates location.

(b) Aerial photo.



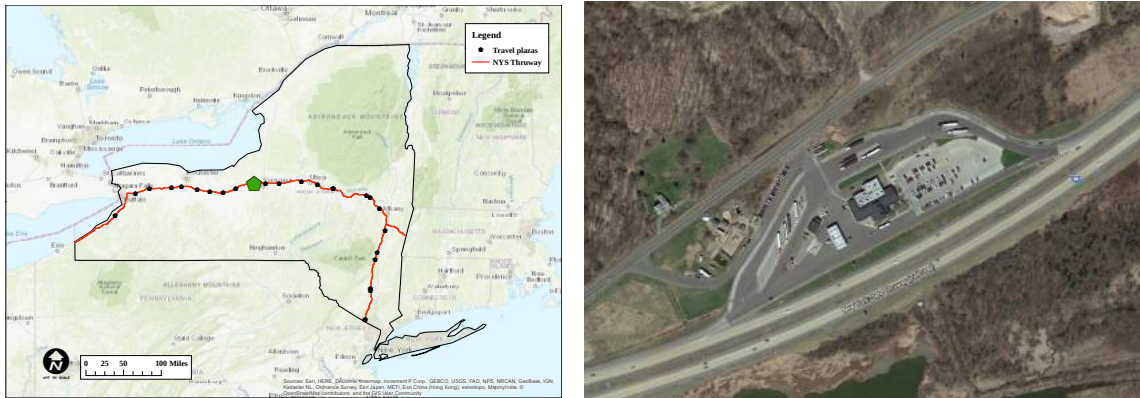
(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

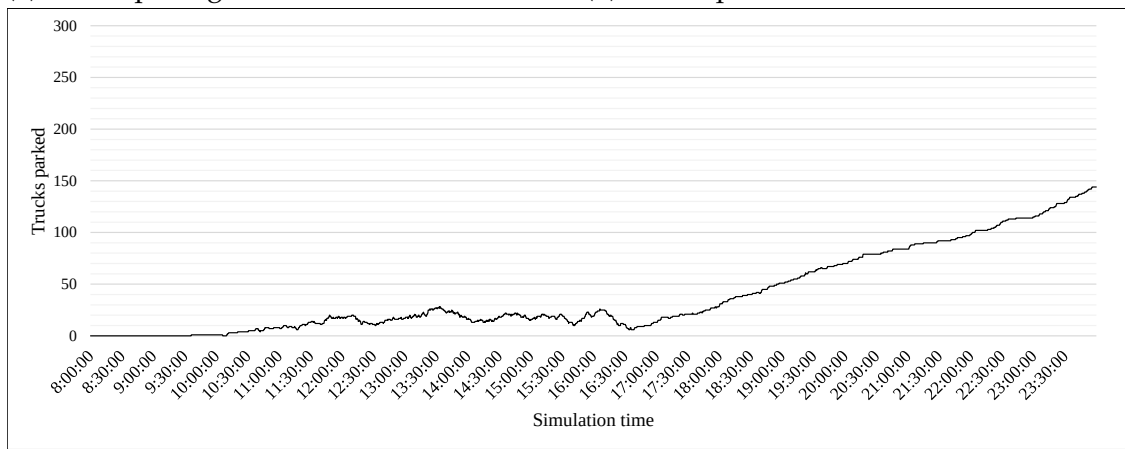
Figure D.26.: Ulster travel plaza.



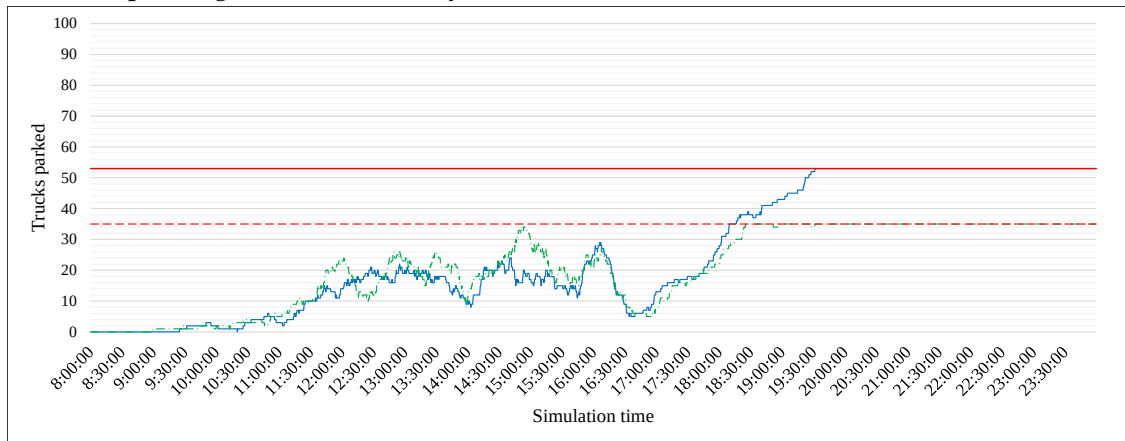


(a) Green pentagon indicates location.

(b) Aerial photo.



(c) Truck parking demand over day.



(d) TPIMS modeling scenario analysis. The solid red line represents maximum truck parking capacity (legal and illegal parking spaces); the dashed red line represents legal truck parking capacity; the solid blue line represents the No-build Scenario, and the dash-dot green line represents the TPIMS Scenario.

Figure D.27.: Warners travel plaza.